HUGO ERKEN

Productivity, R&D and Entrepreneurship

PRODUCTIVITY, R&D AND ENTREPRENEURSHIP

Productivity, R&D and Entrepreneurship

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“An economist is an expert who will know tomorrow why the things he predicted yesterday didn't happen today.”

L.J. Peter (1919-1988)

To my parents

Preface

When I started my job at the Ministry of Economic Affairs in 2002, I did not have a clue that I would wrap up a PhD dissertation by the end of 2008. In fact, because I had just finished research for my Master thesis, I was quite fed up with research in the first place and felt some resistance to start with my new job as a policy researcher. Moreover, I regarded this research position as a steppingstone to a ‘real’ job as a policymaker. Looking back now, this was an error of judgement and research turned out to be much more appealing than I initially could have guessed. Besides, I was quite lucky to be part of a research unit with inspiring people and was able to participate in interesting and challenging projects.

After several years, I began to wonder if it would be possible to write a PhD dissertation. I had already conducted some research at the Ministry that possibly could be used as the first building block for a PhD thesis. I discussed this idea with my unit manager and director, but – despite their support – I could not manage to get things started for at least another year. When frustration really began to build up, I met Roy Thurik in Paris in 2006 at a conference on entrepreneurship organised by the OECD. I spoke with him about possibilities to do a part-time PhD alongside my work at the Ministry of Economic Affairs. Together with my two managers at the Ministry Luuk Klomp and Stephan Raes we made agreements with Roy and in August 2006 I could finally start under his supervision. Roy in this sense was the right person at the right time and I am very grateful to him for giving me the opportunity to realise my ambition to write a PhD dissertation. Acting as my PhD supervisor, Roy has supported me and my research in several ways. He introduced me to many people that are occupied with research on entrepreneurship and he learned me how to manoeuvre in a scientific environment. The discussions with Roy and his critical remarks on my research have also been of great value. Our joint project on determinants of total factor productivity started initially with some setbacks, but Roy always came up with solutions to get the project going and this has resulted in what I believe is the best part of this book (Chapter 9).

There are some people at the Ministry of Economic Affairs that have played a very important role in the realisation of this thesis. I owe much gratitude to Luuk Klomp and Stephan Raes, who created the opportunity for me to combine my work with this PhD project, and provided me with valuable comments and support during to progress of the project. Another person who I am indebted to is my colleague Piet Donselaar. In the years that we have worked together, Piet has always helped me out with research problems and I dare to say that he has taught me more about economics than anyone else. Next to Luuk, Piet, Stephan and Roy, I thank the other co-authors who contributed to chapters of this book: Frank van Es, Victor Gilsing, André van Hoorn, Marcel Kleijn and Martin Ruiter. Many researchers who commented chapters of this thesis are acknowledged for their help.

I would like to thank my (former) colleagues at the Ministry of Economic Affairs and the Erasmus University with whom I had stimulating discussions about innovation, entrepreneurship and subjects that have nothing to do with economics. In particular, my thanks goes to Rob Augusteijn, Jurgen Geelhoed, Marcel de Heide, Philipp Köllinger, Dries van Loenen, all (former) colleagues from the 'soccer'-email list (who often cheered up my Monday mornings), my colleagues of the strategy unit of AEP, Bart Sattler, Willem Spruijt, Sanne Tonneijck, Ingrid Verheul, Jeroen Westerink, Haibo Zhou and Peter van der Zwan. A special thank you to Peter van Bergeijk for his work of art on the cover of this book.

I am also grateful to my family and close friends for providing me with the necessary distraction from work and my research. In particular I want to thank Dax, Eric, CLAUS, Jesse, Harmen, fam. Drost/Heuving, Geertje, Leonie, Marijn, Marlies, Martijn and Ellen, Mathijs, Mattijs, Monique, Nigel, Sander and Tino. A special friend that I would like to thank is my sister Olga for her continuous interest and enthusiasm. I would also like to thank my parents, to whom I dedicate this book for all their love and support. Finally and foremost, I am grateful to Marieke. Her love and understanding was essential for me to complete this thesis.

Hugo Erken
Utrecht, September 2008

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CHAPTER 1

Introduction, framework and main results

1.1 INTRODUCTION

Economists and policymakers have been interested in the sources of economic growth since Adam Smith's 'inquiry into the nature and causes of the wealth of nations' (Smith, 1776). With the development of the neoclassical growth model (e.g. Solow, 1956; Swan, 1956) our understanding of the growth process has advanced significantly. These models explain how labour and capital combine in producing output. Still a significant residual (referred to as total factor productivity (TFP) growth or multifactor productivity (MFP) growth) remained when trying to attribute growth to its underlying sources (Griliches, 1996).

With the development of the endogenous growth theory, knowledge is added to the traditional factors explaining economic growth (Romer, 1986, 1990; Lucas, 1988). The endogenous growth theory attempts to explain the part of growth that could not be attributed to capital and labour inputs. Within endogenous growth models the concept of knowledge spillovers originating from R&D and schooling is introduced, meaning that part of the production of new knowledge at the firm level cannot be appropriated by the firms themselves and spills over into an aggregate knowledge stock that becomes potentially accessible to other firms and agents within a country (ibidem). Knowledge is non-rival and non-excludable by nature, therefore generating positive externalities within an economy (Arrow, 1962a). Knowledge is *non-rival*, because the use of knowledge in one activity does not limit the extent to which it can be used in other activities. *Non-excludability* means that the owner of the good is unable to exclude third parties from using the goods (i.e. paying for it).

Although endogenous growth models have shown much development throughout the 1990s (cf. Jones, 1995; Young, 1998), it proves difficult to empirically estimate these models. The quantification of the knowledge stock used in endogenous growth models is accompanied with statistical difficulties, because this variable is not directly observable. As a consequence, the R&D capital approach is used more often in empirical research (Griliches, 1998, 2000). The greatest source of new knowledge is generally considered to be R&D (Cohen and Klepper, 1992). For this reason and because the calculation of R&D capital is fairly straightforward, the

R&D capital approach is often used in empirical research which endeavours to identify the importance of knowledge creation for economic development. As R&D persistently proves to be an important engine of economic growth (i.e. productivity growth[1]) in the empirical literature (Coe and Helpman, 1995, 2008; Guellec and Van Pottelsberghe de la Potterie, 2004; Jacobs *et al.*, 2002; Griliches and Lichtenberg, 1984; Griliches, 1998; Khan and Luintel, 2006), it is interesting to more closely examine this pillar of growth. Without any doubt, on many aspects of R&D both academics and policymakers are still in the dark. Questions that are frequently addressed and only partially answered are: 'How important exactly is R&D for productivity and consequently for economic growth?', 'What exactly determines R&D expenditure within a country?', 'Does the continuing internationalisation of R&D have consequences for economic growth in countries?' This book sheds more light on the answers to these questions and is an attempt to better understand the role of R&D within the growth process. This is the first goal of the book.

A drawback of the endogenous growth theory is that it fails to describe the actual process of knowledge spillovers. In the Romer (1986, 1990) and Lucas (1988) models knowledge spillovers are regarded as automatic (read: exogenous) and costless. Empirical evidence, however, suggests that knowledge spillovers are bounded by geography and transaction costs (Anselin *et al.*, 2000; Cohen *et al.*, 2000; Jaffe *et al.*, 1993). This also implies that the spillovers of knowledge are not automatic and exogenous, but endogenous. Well-known conduits of knowledge spillovers are the scientific literature and patents (Jaffe *et al.*, 1993; Deng, 2007), networks, spin-offs from firms and knowledge institutions (Audretsch and Feldman, 1996; Powell *et al.*, 1996), and human capital (mobility) (Arrow, 1962b; Moretti, 2004; Moen 2005; Park, 2003).[2] In relation to the R&D capital approach, international trade, foreign direct investments and direct communication are three (international) spillover mechanisms that have been identified in the literature (e.g. Keller, 2001; Branstetter, 2006; Grossmann and Helpman, 1991; Van Pottelsberghe and Lichtenberg, 2001; Lee, 2005; Soete and Ter Weel, 1999).

Entrepreneurship fulfils an important mechanism in facilitating knowledge spillovers (Audretsch and Feldman, 2004; Audretsch, 2007), or as Schumpeter (1947, p. 159) puts it: "*the inventor produces ideas, the entrepreneur 'gets things done'*." Although entrepreneurship is receiving an increasing amount of attention as an engine of growth (Audretsch *et al.*, 2007), the role of entrepreneurship within the process of economic growth is still debated (OECD, 2006). Braunerhjelm (2008) argues that while neoclassical growth theory threats knowledge production as exogenous, knowledge diffusion (i.e. the critical mechanism creating growth) is exogenous in the endogenous theory. Although several attempts have been made to introduce entrepreneurship in endogenous growth models (Segerstrom *et al.*, 1990; Aghion and Howitt,

[1] Economic growth can be broken down in two components, being employment growth and labour productivity growth. Labour productivity growth is defined as the growth of value added per unit of labour.

[2] Although institutions can guarantee excludability to some degree, e.g. the regime of intellectual property rights protects inventions from being used by others; institutions are not an airtight system in preventing the copying of ideas.

1998), these endogenous growth models disregard the essence of the Schumpeterian entrepreneur (Braunerhjelm, 2008, p. 475).[3] Audretsch *et al.* (2006) and Acs *et al.* (2004, 2005) try to overcome this limitation of the endogenous growth theory by introducing the notion of a *'knowledge filter'* that prevents knowledge from becoming economically useful. The idea is that not all created knowledge is economically relevant (Arrow, 1962a). Parts of the total knowledge stock have to be transformed into economic relevant knowledge that is suitable to the firm that wants to use it. Transforming 'raw' knowledge into firm-specific knowledge takes efforts and costs. In this sense the knowledge filter can be interpreted as a barrier impeding investments in new knowledge from spilling over for commercialisation (Audretsch, 2007). The knowledge filter must be penetrated in order to adjust knowledge before it can contribute to economic growth. Actors that are willing to penetrate the knowledge filter are incumbent and new firms. Incumbent firms have the capabilities to penetrate the filter (Cohen and Levinthal, 1990) and new firms are eager and motivated to do the same in order to force market entry or capture market share (Kirzner, 1997). In other words: entrepreneurship is an important mechanism that permeates the knowledge filter, facilitating the spillover of knowledge and ultimately generating economic growth (Audretsch, 2007).

It proves, however, difficult to break in into endogenous growth theory and the attempts thus far are not really convincing. From an empirical point of view, there is much more evidence that entrepreneurship is related to economic growth (Audretsch and Thurik, 2001a; Carree and Thurik, 2003; Van Stel *et al.*, 2005; Audretsch and Keilbach, 2004a, 2004b, 2004c; Thurik *et al.*, 2008). However, there is no study available that shows a long-run relationship of entrepreneurship with productivity development for an international panel of OECD countries. Bleaney and Nishiyama (2002) empirically test various growth models, but none of these models contain entrepreneurship as a determinant. Van Praag and Versloot (2007) provide a literature overview on the relationship between entrepreneurship and economic variables, but they do not find a study that examines the long-run relationship between entrepreneurship and productivity, either from a static or from a dynamic perspective. Holtz-Eakin and Kao (2003) relate the birth and death rate across US states to the 'within' variation of productivity. The effects of the lagged values of the birth and death rate on productivity are insignificant and show negative signs.[4] Carree and Thurik (2008) discriminate between the short and long run effect of new business creation on productivity, but they only find a significant positive effect of entrepreneurship in the short term. It is striking that Schumpeter (1912) wrote his pioneering work on entrepreneurship almost a hundred years ago, but entrepreneurship fails to reveal its

[3] The neo-Schumpeterian models primarily design entry as an R&D race between existing firms where only a small part of total R&D efforts will result into actual innovations. Braunerhjelm (2008) argues that innovation processes encompass much more than solely R&D races between large incumbents which concern quality improvements of existing goods.

[4] Holtz-Eakin and Kao (2003) do find a significant positive relationship between birth and death rates and productivity levels in cross-section panel estimations. However, these estimation results are vulnerable to possible unobserved heterogeneity. In addition, the cross-section estimations are not the preferred regression results by the authors either.

importance within theoretical models (i.e. endogenous growth models) or long-run empirical exercises trying to explain growth. The second goal of this book is to examine the importance of entrepreneurship, amongst other drivers, as a structural source of growth (i.e. productivity development).

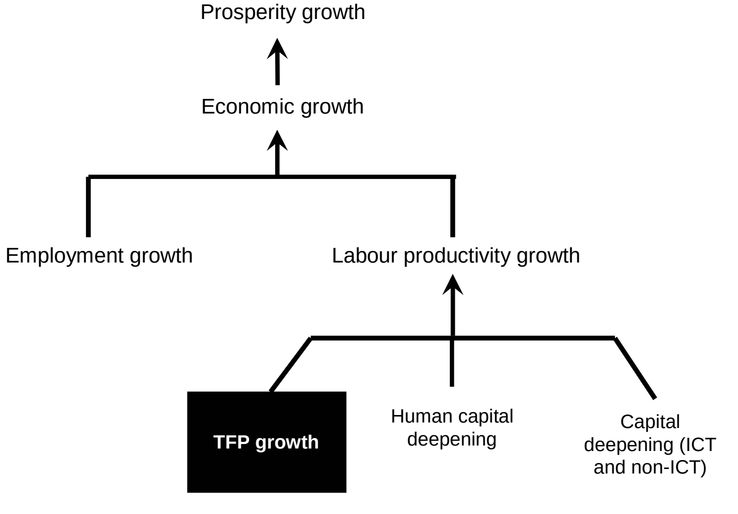
To recapitulate, this dissertation provides a closer look how knowledge creation through R&D leads to productivity growth. Next, it seeks to find out the role of entrepreneurship within the growth process. The remainder of this chapter is structured as follows. Section 1.2 presents a framework that enables to systematise the several chapters in relation to each other. Section 1.3 discusses the chapters individually by providing the main research results of each chapter. In Section 1.4 options for future research are addressed. Finally, Section 1.5 gives an overview of the publication status of each individual chapter.

Three general remarks on the structure of the dissertation are well worth mentioning. First, the book is a combination of separate studies. Each chapter is based on one of these studies and therefore is readable in itself. This implies, however, that we sometimes cope with doubling of information in this book. For instance, the development of the private R&D intensity is separately presented in many chapters to set the stage. Second, the time sequence of the research presented in this dissertation has to be taken into account. To give an example, Chapter 4 only briefly discusses the topic of internationalisation of R&D, as research on this topic had just started when this chapter was written, whereas Chapter 8 presents an overview of all information that was available on internationalisation of R&D at a much later stage. The same counts for the explanation of productivity. In Chapter 3, the development of total factor productivity (TFP) is related almost solely to R&D, whereas in Chapter 9, the model to explain TFP covers a much broader spectrum of determinants. In this sense, both Chapters 3 and 4 were the first conducted studies of this book. Despite attempts to update the literature and data in these chapters, they may still contain some outdated elements. Third, Chapter 9 is the most recently written chapter of this book and combines much of the knowledge on drivers of productivity that was gathered throughout the period that this book was written.

1.2 FRAMEWORK

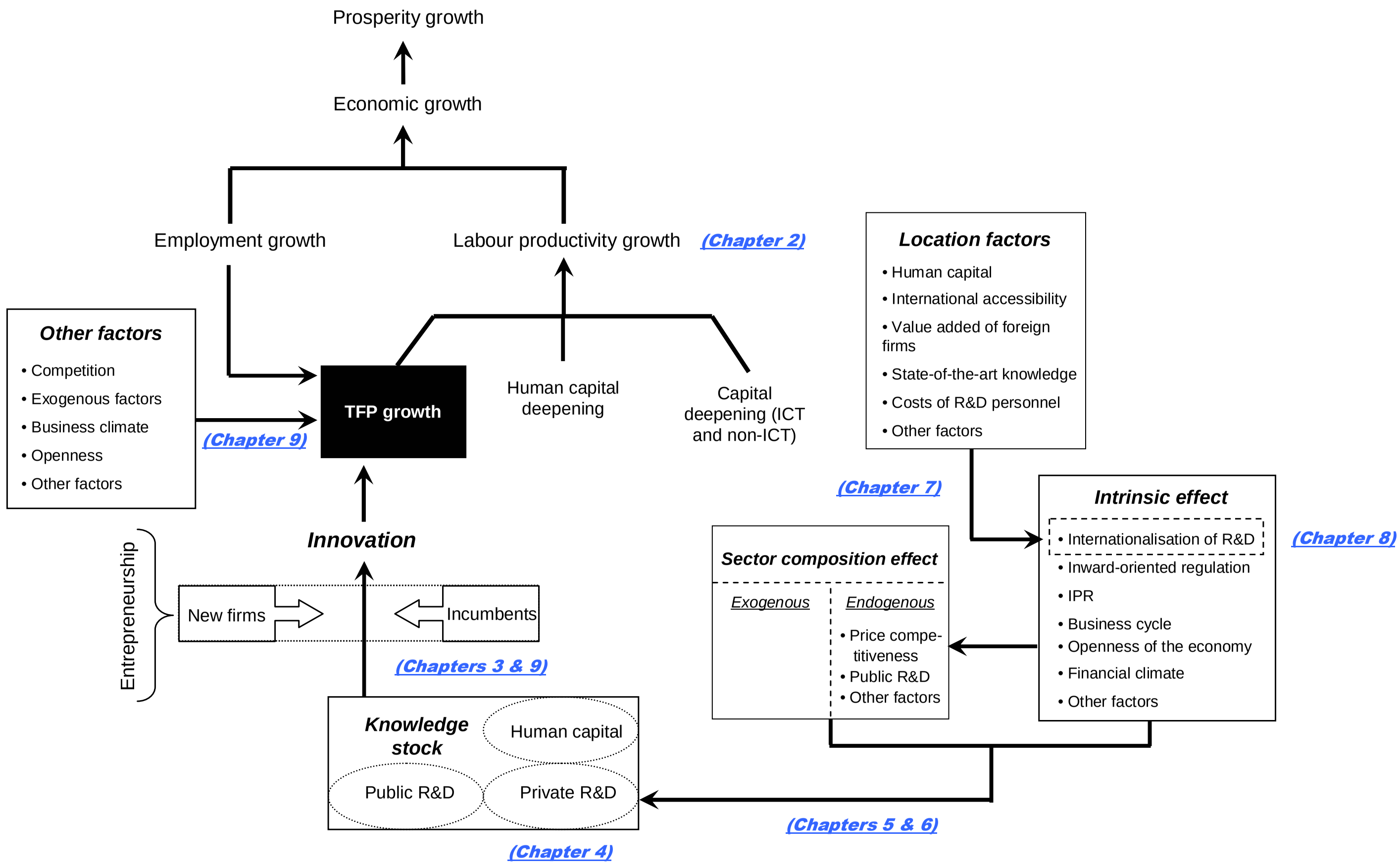
This section presents a framework how to break down economic growth into various factors. Figure 1.1 represents a ‘basic text book’ framework on economic growth, inspired on the growth accounting methodology, where economic growth is decomposed into several input factors (see, e.g., Solow, 1956, 1957; Kendrick, 1961; Jorgenson and Griliches, 1967). In Figure 1.1, economic growth – growth of gross domestic product (GDP) – is dependent on growth of employment and growth of labour productivity, i.e. growth of value added per unit of labour. Based on the neoclassical growth theory, labour productivity growth depends on three drivers. First, this is (physical) capital deepening, which is defined as the growth of the amount of physical capital (both ICT capital and non-ICT capital) per unit of labour. A second source of productivity growth is human capital deepening, which refers to quality improvements of labour due to education and training. More in general, Van Bergeijk *et al*. (1997) define human capital as a public good that is provided to the individual firm and represents the average stock of knowledge in society, embodied in all people in the work force. The third engine of productivity growth is total factor productivity (TFP) growth or multifactor productivity (MFP) growth. TFP growth is the part of economic growth that cannot be attributed to either labour (i.e. employment growth or human capital deepening) or capital. Therefore, TFP growth is measured as a residual within the growth accounting methodology. Abramovitz (1956) strikingly refers to TFP as a 'measure of our ignorance'.

Figure 1.1 Decomposition of economic growth



Exposing the main drivers of TFP, with an emphasis on the role of R&D and entrepreneurship, touches the main objective of this dissertation. In Figure 1.2, Figure 1.1 is extended by schematically introducing the determinants of TFP growth, as well as some determinants of these drivers. The framework depicted in Figure 1.2 is a static and basic way to look at the various determinants of economic growth and TFP growth in particular. Therefore, the framework should be considered as a simplified semi-intuitive representation of how various topics in this book are organised in different chapters.

Figure 1.2 Graphical presentation of economic growth process



Total factor productivity growth is largely dependent on innovation (e.g. Baumol, 2002).[5] Innovation, in turn, is subject to the development of knowledge, with human capital and R&D as the fundamental drivers. Knowledge, however, does not automatically generate growth and transmission mechanisms are needed to transform 'raw' knowledge into actual innovations. The bottom-left corner of Figure 1.2 illustrates how entrepreneurship constitutes an important mechanism for productivity growth. Both new and incumbent firms are willing to make costs and effort to convert knowledge into economically relevant knowledge. The idea is that only a part of the total knowledge stock, i.e. economically relevant knowledge, can lead to innovations which spurs total factor productivity growth and entrepreneurs are necessary to fulfil this transfer.

R&D and entrepreneurship are not exogenous and constitute complex phenomena. Although little notice is taken of the determinants of entrepreneurship in this book (for further reading see, for instance, Wennekers, 2006; Parker and Robson, 2004; Evans and Leighton, 1989; Uhlaner and Thurik, 2007; Grilo and Thurik, 2005a, 2005b; Armington and Acs, 2002), the drivers of private R&D are examined more thoroughly (see the right-hand side of Figure 1.2). First of all, private R&D depends on the *sector composition effect*. The sector composition effect compares the share of knowledge-intensive industries within the overall economic structure between countries or regions. The complement of the sector composition effect is referred to as the *intrinsic effect* and represents the within-industry effect. Although the sector composition of a country can not be changed in the short term, it is, however, not completely exogenous and is influenced by, amongst other things, the intrinsic effect, price competitiveness and public R&D. The intrinsic effect, in turn, is dependent on many factors, of which the internationalisation trend of R&D is one of the most interesting. Therefore, this characteristic of private R&D is more closely examined, including the location factors of private R&D.

The elements mentioned above are some of the most important mechanisms of productivity growth that will be dealt with in this book. The individual chapter that reflects on a certain mechanism or combination of mechanisms is shown in the framework. In the next section we will discuss the main research questions addressed in these individual chapters as well as some of the results that provide answers to them.

1.3 MAIN RESULTS AND STRUCTURE OF THESIS

Chapter 2 presents an international comparison of Dutch productivity performance over the last 35 years, with an emphasis on the period after 1995. Productivity differentials are analysed from a macroeconomic view, as well as from an industry-level perspective. From a macro

[5] Other factors are important for TFP as well, such as competition and the openness of the economy (see the box 'other factors' in Figure 1.2). The impact of competition on innovation has been studied extensively by others (see, for instance, Aghion *et al*., 2001; Boone, 2000, 2001).

perspective, we observe a possible trade-off between productivity and participation. From an industry-level perspective, the sector composition of the Netherlands does not prove to be an important factor in explaining productivity growth differences with other countries. Growth decomposition exercises on the macro and industry level are conducted to shed light on the major drivers of productivity: (physical) capital deepening (both ICT and non-ICT), human capital deepening and total factor productivity. Discrepancies in total factor productivity growth provide the major explanation behind dissimilarities in productivity growth patterns between countries.

In Chapter 3 a first step is taken to examine what factors determine the development of total factor productivity. Based on the existing literature, the impact of R&D and innovation as drivers of productivity is more closely examined. Calculations show that R&D and innovation account for (at least) 40 percent of labour productivity growth in the Netherlands during the 1990s. Moreover, productivity in the Netherlands might well benefit from a structural increase in private R&D expenditure measured as a percentage of GDP. Raising private R&D expenditure in the Netherlands from 1.0% to 2.0% of GDP, in line with the Barcelona ambition of the EU, might lead to an increase in labour productivity of about 7%.

Chapter 4 describes some general trends in corporate R&D. It combines a macroeconomic perspective, based on aggregated national data, with a micro perspective, based on the managerial trade-offs in organising the R&D process. The macro picture of Dutch R&D is a fairly ‘calm’ one: a steady rise of absolute R&D expenditure rising proportionally with GDP and no systematic relocation of R&D. However, underneath this relatively ‘smooth surface’ the situation is highly dynamic and heterogeneous. At the micro level we see increasing competition and an ongoing acceleration of product and technology cycles. For firms the most important strategic question is how to increase the speed and creativity of R&D, and the total innovation process. The way in which this is done varies considerably from industry to industry and between companies, making it difficult to identify universal trends. However, one emerging trend which seems to cross sector boundaries is the growing significance of state-of-the-art knowledge, as well as the growing importance of having *access* to such knowledge, wherever it is located around the globe.

In Chapter 5 a methodology is introduced how to decompose differences in corporate R&D between countries or groups of countries. Applying this methodology to the Dutch situation, we can illustrate that roughly 60% of the total private R&D shortfall of the Netherlands compared to the OECD average is the result of a knowledge-extensive sector composition. In addition, we show that the sector composition of a country is not fixed, but in fact endogenous. The remaining 40% of the Dutch R&D shortfall is caused by relatively low foreign R&D investments (adjusted for the openness of the economy). In Chapter 6 the decomposition methodology from Chapter 5 is applied on the private R&D difference between the EU15 and the US. The empirical results reveal that the difference in economic structure between the EU15 and the US barely plays a role of significance. Instead, the European private R&D shortfall is mainly caused by a negative intrinsic effect, meaning that companies within European industries spend less on R&D than their US peers in the same sectors. This negative intrinsic effect is mainly due to institutional differences between the US and the EU15, especially product market regulation and the intellectual property rights (IPR) regime.

Chapters 7 and 8 take a closer look at several aspects and consequences of the internationalisation of R&D, as this phenomenon increased considerably during the second half of the 1990s. Chapter 7 mainly focuses on location factors of R&D investments using an multi-level perspective encompassing a literature review, a field study and an econometric analysis using international panel data. The results show that the most important location factors for R&D are: (1) *the availability of qualified personnel*, (2) *the stock of private R&D capital*, (3) *the value added of foreign firms*, (4) *international accessibility* and (5) *the quality of knowledge institutions.* A clear view on the most important location factors is crucial to attract new foreign investments in R&D and to keep home-based R&D activities in a country or to expand them. Chapter 8 more generally focuses on the internationalisation of R&D as a trend. In the Netherlands, as much as elsewhere, this trend is generally considered a threat in terms of losing key inputs for innovation and future economic growth. In this chapter we criticise this view for being one-sided as it overlooks the fact that countries can also benefit from internationalisation. Moreover, we argue that globalising R&D particularly affects small and open economies.

In Chapter 9 we broaden our view on determinants of total factor productivity again by using six different models based on the established literature. Traditionally, entrepreneurship is not dealt with in empirical models explaining TFP. In this chapter it is shown that – when this variable is added – in all models there is a significant influence of entrepreneurship, while the the effects of other variables remain stable. Entrepreneurship is measured as the business ownership rate (number of business owners in relation to the workforce) corrected for the level of economic development (GDP per capita). The empirical estimations in this chapter result in one comprehensive model in which all separate drivers of TFP are included. The results show that almost every variable in the comprehensive model – including entrepreneurship – has an expected and significant effect on TFP. Although entrepreneurship in Chapter 9 is identified as a significant driver of total factor productivity, the interaction between entrepreneurship and R&D, which exemplifies the idea of entrepreneurship as a transfer mechanism of spillovers described in Sections 1.1 and 1.2, is not found in this chapter. This could indicate that entrepreneurship does not lead to a permanent higher *growth* of total factor productivity, just like a higher R&D intensity does not lead to a permanent higher growth of productivity (see Young, 1998; Jones, 1995; Donselaar *et al*., 2003).[6] Entrepreneurship does, however, have a

6 A positive interaction effect of entrepreneurship on the effect of domestic and foreign R&D capital implies that productivity growth would rise permanently, as stocks of domestic and foreign R&D capital show a trend-related increase. In case of levels, the interaction of entrepreneurship with the stocks of domestic and foreign R&D capital is already expressed in our log-linear estimation method.

structural impact on the *level* of productivity. This is evidences by the fact that the estimated log-linear relationships in Chapter 9 can be rewritten to multiplicative relationships expressed in levels. In these multiplicative relationships, the impact of domestic and foreign R&D capital on the level of productivity increases progressively when the (adjusted) entrepreneurship variable shows a higher rate.

1.4 OPTIONS FOR FUTURE RESEARCH

A number of questions that prompt from the research in this book provide ground for further research. First of all, the role of entrepreneurship as a conduit of knowledge spillovers could be examined more closely by interacting R&D and entrepreneurship within a model explaining innovation. If entrepreneurship is an important mechanism that permeates the knowledge filter and facilitates knowledge spillovers (see Section 1.1), consequently entrepreneurship has to interact with other drivers of growth in order to expose its relevance for total factor productivity development, especially R&D. The idea of using an interaction variable for entrepreneurship is that the impact of domestic and foreign R&D on productivity of a country is partly dependent on the amount of entrepreneurial energy in that country. Taking this mechanism in consideration, we experimented with entrepreneurship interaction variables in our empirical analyses explaining total factor productivity development in Chapter 9. The Community and Innovation Survey (CIS), co-ordinated by Eurostat, opens up possibilities to study the determinants of innovation output, most preferably *turnover due to new and significant products*. There are several cross-sectional studies (see, for instance, Faber and Hesen, 2004; Mohnen *et al.*, 2006; Jaumotte and Pain, 2005) that try to explain the share of turnover due to new or significantly improved products. These studies however, cope with difficulties in causality which distort the regression outcomes. There are virtually no studies available that examine the drivers of innovation expressed by the variable turnover due to new or significantly improved products in a longitudinal setting. As the results from four CIS waves are available, there are possibilities to examine the drivers of innovation for a panel of countries and years.

Second, it is worthwhile examining the relevance of a two equation model where productivity is a function of entrepreneurship, among other drivers, and entrepreneurship is a function of the level of economic development, among other drivers. In the setup of Chapter 9 we apply such a model but in a recursive fashion and with GDP per capita as the sole determinant of entrepreneurship. Simultaneous equation effects and the various determinants of entrepreneurship are not investigated. Another extension of the research in Chapter 9 would be to adopt the institutional variables from Coe, Helpman and Hoffmaister (2008). Coe *et al.* (2008) recently published a revisited version of the Coe and Helpman study from 1995. In addition to R&D variables, Coe *et al*. (2008) include several institutional variables which are absent in the analysis in Chapter 9, such as legal origin and patent protection. The results from their empirical study show that institutional differences are important determinants of total factor productivity development. Therefore, it would be interesting to adopt Coe *et al*. (2008) as the sixth strand of literature to be investigated.

1.5 PUBLICATION STATUS OF CHAPTERS

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- Revised version of book publication: An international comparison of productivity performance: the case of the Netherlands, in: G.M.M. Gelauff, L. Klomp, S.E.P. Raes and T.J.A. Roelandt (eds.), *Fostering Productivity. Patterns, Determinants and Policy Implications*, Elsevier, Contributions to Economic Analysis 263, 2004, pp. 9-28.
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Chapter 3: *R&D and innovation: drivers of productivity growth*

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Chapter 4: *Trends in R&D – A Dutch perspective*

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Chapter 5: *Anatomy of private R&D expenditure: An explanation of the Dutch R&D shortfall based on empirical evidence*

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CHAPTER 2

An international comparison of productivity performance: the case of the Netherlands

2.1 INTRODUCTION

Productivity performance differs considerably, over time and between countries. As a consequence, there are substantial variations in the contribution of productivity (in addition to labour market participation) to economic growth, which makes productivity performance of interest to both researchers and policymakers. During the second half of the 1990s, productivity differentials were in the spotlight, in what became known as the *new economy*. Although the sharp decline in stock market prices for ICT companies since then has certainly taken away some of its glamour, the continuing productivity performance of the US compared with its European competitors remains a startling feature. Productivity in the EU is at the forefront of the Lisbon agenda, which aims to make Europe the most competitive economy in the world by 2010.

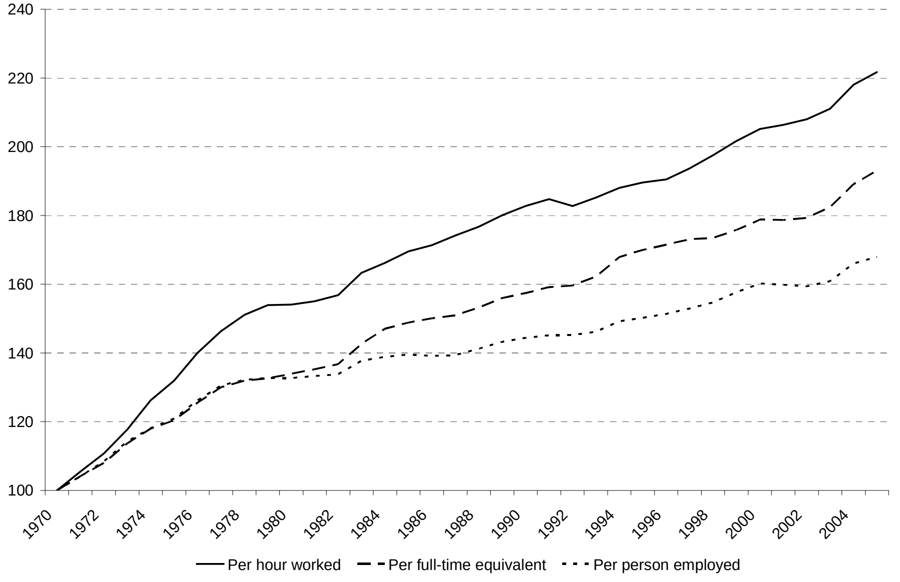
This chapter provides a systematic overview of international productivity performance of the Netherlands vis-à-vis a number of other OECD countries, at both the macro and the industry level. The analysis covers the last three and a half decade, with an emphasis on the period since 1995. The data used in this chapter were compiled from various databases, mainly the EU KLEMS database (March 2008 release, http://www.euklems.net). Additional data was taken from the OECD Economic Outlook database (https://www.oecd.int/olis/portal/site/olisnet) and the Total Economy Database from The Conference Board and Groningen Growth and Development Centre (http://www.conference-board.org/economics). The chapter also presents some preliminary observations on the contributions of both productivity and participation to economic growth, and the possible trade-offs involved.

Section 2.2 of this chapter discusses differentials in macro productivity levels, followed by an analysis of macro productivity growth. Section 2.3 deals with differences at the industry level. This includes a shift-share analysis in order to assess to which extent productivity growth differentials between the Netherlands and other countries are the result of differences in (changes in) sector composition. Section 2.4 gives economic explanations of the observed productivity patterns using the growth accounting methodology. Finally, Section 2.5 concludes the chapter and presents a number of implications of potential interest to policymakers.

2.2 PRODUCTIVITY PERFORMANCE AT THE MACRO LEVEL

Labour productivity is defined as the amount of value added per unit of labour. Within statistics, labour productivity is expressed in three different ways: per person employed, per full-time equivalent (FTE) and per hour worked. Figure 2.1 shows labour productivity development in the Netherlands according to these three criteria. Labour productivity *per hour worked* is the most relevant indicator to measure the productivity capacity of countries (OECD, 2001). Therefore, we use this indicator of productivity whenever we speak of productivity in the remainder of this thesis.

Figure 2.1 Development of labour productivity in the Netherlands, 1969-2006; 1969 = 100



Source: calculations based on data from the EU KLEMS database (March 2008 update); data about employment per full-time equivalent from Statistics Netherlands (http://www.cbs.nl).

2.2.1 Levels of productivity

Table 2.1 breaks down gross domestic product (GDP) per capita in its various components: the employment rate (column (B)), the number of hours worked per person employed (column (D)) and labour productivity per hour worked (column (E)).

Table 2.1 Decomposition of GDP per capita, 2005

Volumes in prices of 2005, converted using German euro purchasing power parities (€PPP)

	Volume GDP per capita	**Persons employed in relation to total population**	**Volume GDP per person employed**	**Hours worked per person employed**	**Volume GDP per hour worked**
	(A)	**(B)**	**(C)**	**(D)**	**(E)**
Australia	27,933	0.50	55,905	1797	31.3
Austria	24,286	0.51	47,551	1656	28.7
Belgium	25,262	0.41	61,966	1447	42.8
Canada	29,662	0.49	59,959	1764	34.0
Cyprus	19,129	0.42	45,830	1833	25.0
Czech Republic	15,845	0.49	32,516	1965	16.5
Denmark	27,966	0.51	54,994	1541	35.7
Finland	25,540	0.46	55,640	1718	32.4
France	22,743	0.41	55,623	1550	35.9
Germany	24,504	0.47	52,165	1435	36.4
Greece	16,640	0.38	43,635	2091	20.9
Ireland	33,217	0.48	69,212	1881	36.8
Italy	22,577	0.42	53,912	1818	29.7
Japan	21,276	0.50	42,461	1707	24.9
Republic of Korea	19,467	0.47	41,428	2211	18.7
Luxembourg	53,821	0.66	81,951	1682	50.3
Mexico	9,363	0.39	23,882	2179	11.0
Netherlands	**27,103**	**0.50**	**54,028**	**1392**	**38.8**
New Zealand	23,090	0.52	44,765	1750	25.6
Norway	42,806	0.51	83,593	1420	58.9
Portugal	16,302	0.48	33,654	1842	18.3
Spain	21,667	0.44	49,413	1669	29.6
Sweden	26,923	0.48	55,727	1605	34.7
Switzerland	32,086	0.56	57,454	1556	36.9
United Kingdom	24,620	0.48	50,810	1673	30.4
United States	36,076	0.51	70,642	1791	39.4
EU15	24,007	0.45	53,258	1617	32.9
OECD	23,923	0.46	51,721	1781	29.2

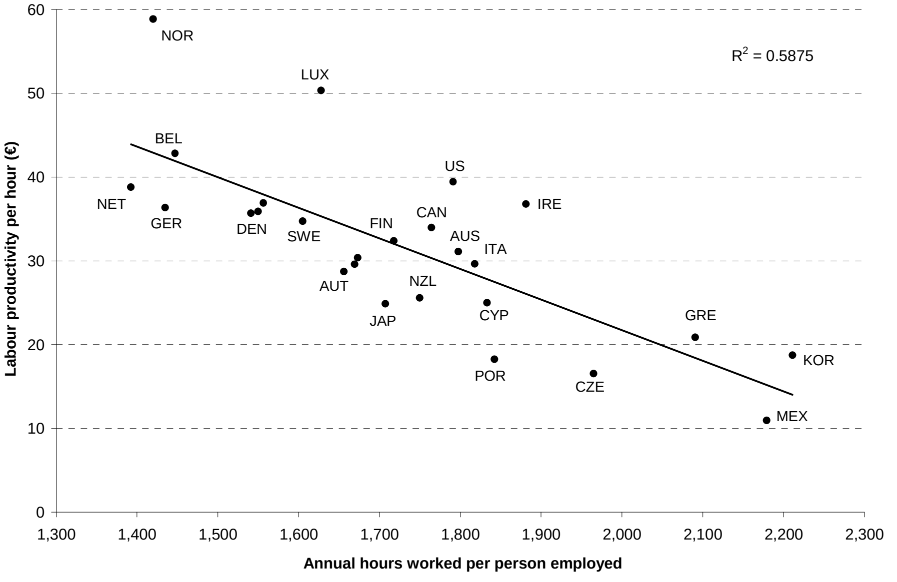
Commentary: column (A) = column (B) × column (C); column (C) = column (D) × column (E). Calculating the figures for column (A) and (C) based on the reported figures in the table leads to slightly different outcomes due to rounding off.

Source: the EU KLEMS database (March 2008 update) was used to collect data for the EU27 countries, Australia, Japan, the US (NAICS based) and the EU aggregate. Population data for all countries are derived from the Total Economy Database (January 2008) of The Conference Board and Groningen Growth and Development Centre. For Canada, Mexico, New Zealand, Norway, the Republic of Korea and Switzerland value added data is taken from the OECD Economic Outlook database (no. 82). Data regarding the number of people engaged in employment and the number of hours worked originate from the Total Economy Database.

In terms of GDP per capita, the US clearly outperforms its OECD partners, with the northern European countries at approximately three-quarters of the US level. To a large extent the differences in GDP per capita are related to divergent patterns of labour market participation, in terms of (in)activity levels (denoted by the employment rate; Column B of Table 2.1) and the number of hours worked per person employed (Column D).

Whereas the US ranks high on both these participation indicators, and on productivity per hour, Austria, Japan, New Zealand, Korea and Portugal all combine high levels of employment and hours worked with relatively low productivity per hour. At the other end of the spectrum, Belgium and France achieve high levels of productivity, but score less well in terms of participation. The Netherlands constitutes an interesting case, since it combines high levels employment and a strong performance in productivity per hour worked with the lowest number of hours worked within the entire OECD. Only Norway shows a similar situation.[7] Therefore, in terms of the level of productivity per hour, there is no such thing as a productivity problem for the Netherlands.

Figure 2.2 Annual number of hours worked per person employed and labour productivity per hour (2005)



Source: Table 2.1. Commentary: some countries are not labelled in the graph.

7 Norway has an exceptional high level of productivity. This is due to a highly capital-intensive structure with the focus on three industries: oil, timber and fisheries (see Bourlès and Cette, 2007).

Differences in the sources of the level of economic development are not simply of interest because they enable the identification of future policy challenges related to participation or productivity. It is also possible that they might have implications for trade-offs *within* economic policy. Arguably, low participation rates can be related to high productivity levels, through the capital-labour ratio, the expulsion of less qualified labour and investments in human capital. In addition, the scale of part-time labour might have an impact on productivity. As Figure 2.2 points out, there is a negative correlation between the number of hours worked per person employed and productivity per hour worked. Countries with a low number of hours worked, enjoy, on average, higher levels of productivity per hour.

Although we do not find the same strong graphical correlation between productivity levels and the employment ratio (people engaged in work as a share of total population), recent empirical research has shown that a trade-off between productivity and the employment rate also exists (cf. Bourlès and Cette, 2007; Belorgey *et al*., 2006; Donselaar and Segers, 2006).[8] Bourlès and Cette (2007) conclude that one point variation of the employment ratio changes hourly productivity in the long run by -0.43 percent. In addition they find that 1 percentage variation of hours worked per person employed changes long-run productivity per hour worked by -0.42. These effects are in accordance with the estimated effects of the employment rate on productivity found by Donselaar and Segers (2006) and Belorgey *et al*. (2006).[9] Chapter 9 of this dissertation also provides empirical evidence of the negative relationship between participation (from the perspective of hours worked as well as the employment rate) and the development of productivity levels.

For the Netherlands it is interesting that an adjustment for the low amount of hours worked places the country at a considerably lower rank vis-à-vis other OECD countries. A recent study by Bourlès and Cette (2007) shows that the productivity level of 13 OECD countries compared with the US level drops substantially if the initial productivity level of each country is adjusted for the negative impact of the amount of hours worked. As to the Netherlands, the "structural" productivity level drops 10% compared with the "observed" productivity level.

2.2.2 Productivity growth

Figure 2.3 shows that, at least in the last decade, productivity growth has been a more important source of GDP per capita growth than employment growth. The exception is Spain where a large positive contribution of participation growth principally resulted in higher GDP per capita growth. Furthermore, the graph shows that, except for Denmark, each country experienced a

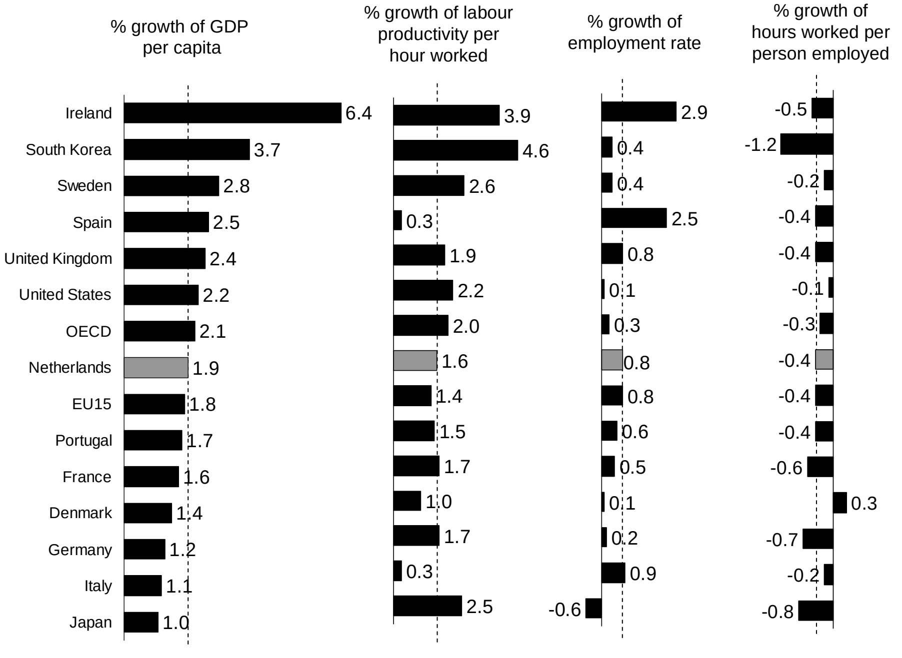
[8] McGuckin and Van Ark (2005) suggest, however, that in the longer term, the trade-off between productivity and participation is less prominent. They also find little effect of hours per worker on productivity.

[9] Donselaar and Segers (2006) find a long-run elasticity for the impact of hours worked on labour productivity of -0.45 and an elasticity for the employment ratio of -0.37. In addition, the elasticities found by Belorgey *et al.* (2006) are -0.37 for the impact of hours worked on long-run productivity and -0.50 for labour participation (see Annex 2 of Chapter 9 for a derivation of the elasticities).

negative contribution of declining number of hours worked per person employed on GDP per capita growth.

Figure 2.3 Decomposition of GDP per capita growth, 1995-2005

Volumes, average annual percentage change

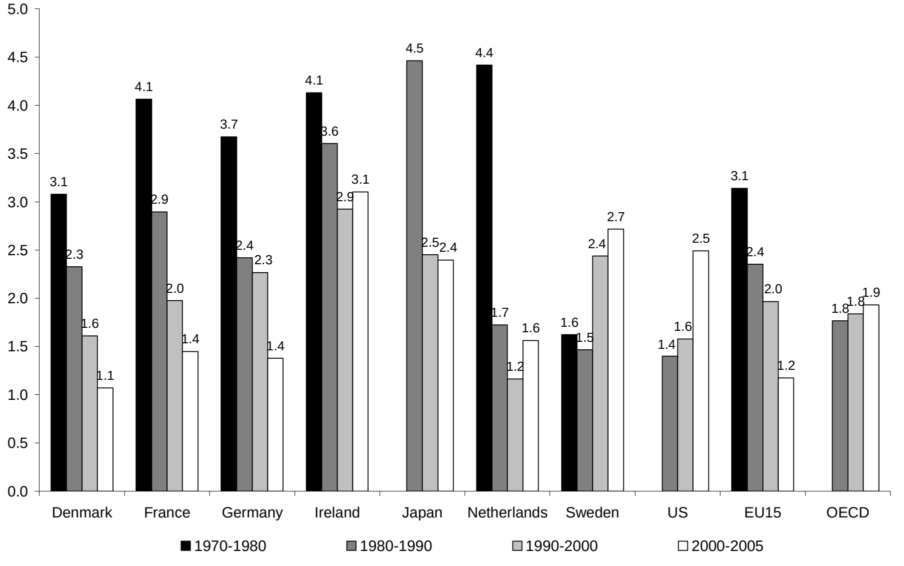


Source: calculation based on data from the EU KLEMS database (March 2008 update), the Total Economy Database (Conference Board and Groningen Growth and Development Centre) and the OECD Economic Outlook database (no. 82).

Figure 2.4 depicts labour productivity growth in several sub-periods between 1970 and 2005. Productivity growth in the EU15 slowed down considerably over time to 1.2% annually between 2000 and 2005. Denmark, France and Germany reveal the same downward trend in productivity growth. In contrast, Ireland, Japan and the OECD are able to maintain fairly high growth rates and some countries, e.g. Sweden and the US, even show rapid acceleration of productivity growth in the last five years. The Netherlands is somewhere in between both extremes. Whereas during the 1980s and 1990s productivity growth per hour in the Netherlands was lower than in most other OECD countries, it picked up again to 1.6% annually in the period 2000-2005.

Figure 2.4 Growth of labour productivity per hour worked, 1970-2005

Volumes, average annual percentage change



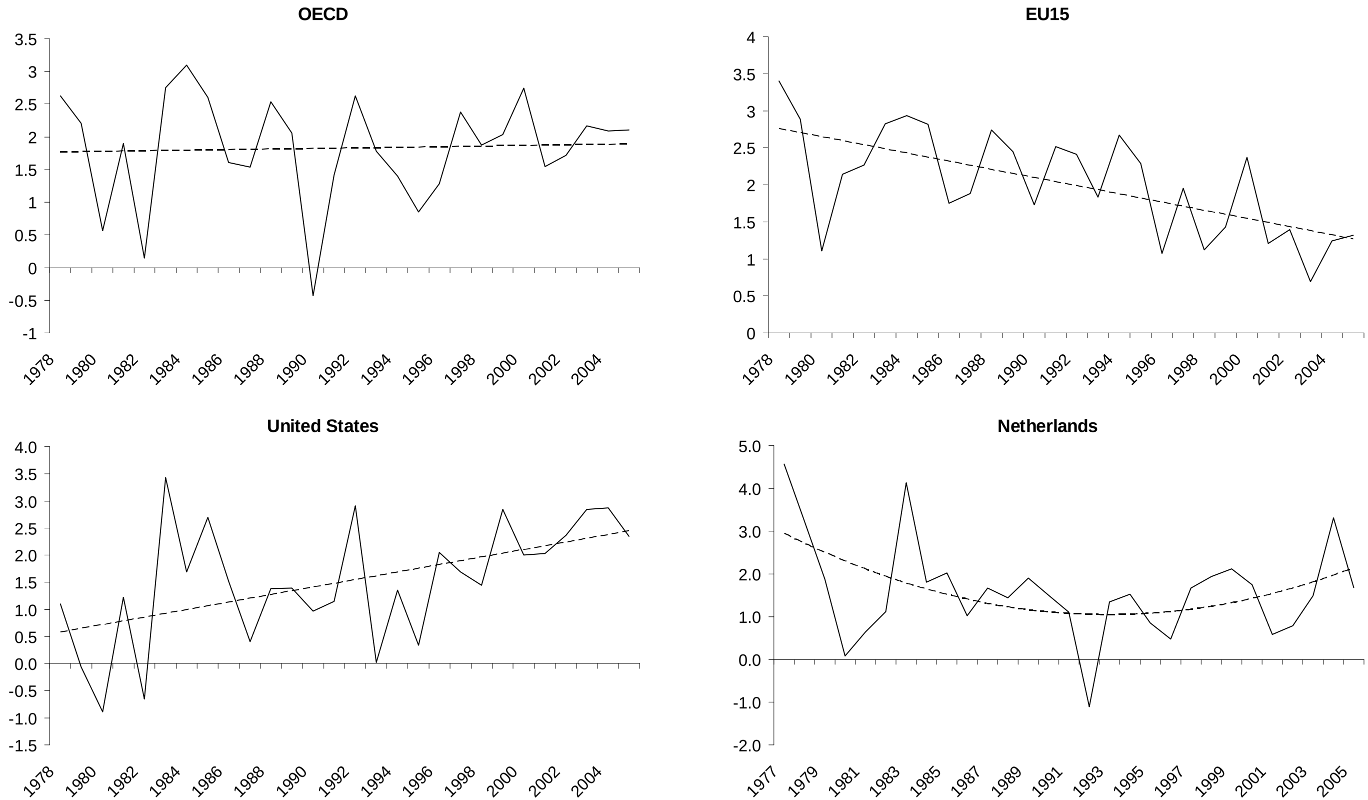
Source: calculations based on data from the EU KLEMS database (March 2008 update). Data for Czech Republic and Cyprus are included in the OECD average after 1995. Data for Poland and Hungary were included in OECD average in the periods after 1990 and 1991 respectively.

Figure 2.5 illustrates growth mutations on an annual basis for the OECD average, the EU15, the US and the Netherlands. The OECD average has a fairly stable growth path over time: the trend is nearly horizontal. The EU15 shows a downward trend of productivity growth over time, whereas the US exhibits the reverse. The US has a unique position in this sense, as it demonstrates continuous higher productivity growth from a starting point of high productivity as well as participation levels. The Netherlands growth pattern has a U-shape: annual productivity growth declined up till 1992, but, as in the US, has been speeding up since then.

Leaving aside the exceptional productivity performance of the US, the potential trade-off between participation and productivity might have more dynamic implications in general. For instance, the Netherlands witnessed a strong increase in participation levels during the 1990s, which was, to a considerable extent, caused by the growth of (part-time) employment of less-skilled workers. As a result of this, and of the general reduction in the length of the working week, the average number of hours worked declined.[10]

[10] This process had already started in the Netherlands during the 1980s, considerably earlier than in most other European countries.

Figure 2.5 Annual growth of labour productivity per hour worked, 1978-2005

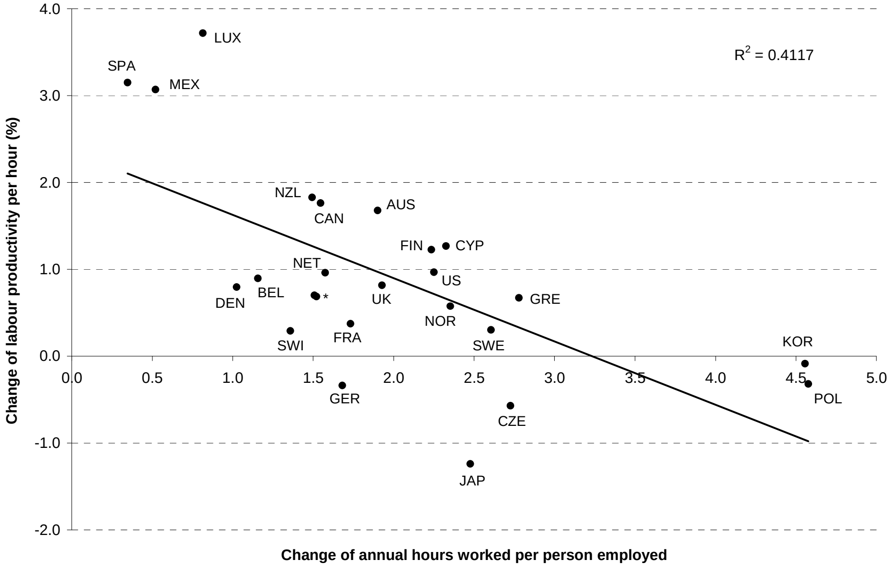


Source: calculations based on data from the EU KLEMS database (March 2008 update).

More people working constituted the main reason for the significant acceleration of economic growth in the second half of the 1990s. However, growth of productivity *per person employed* slowed down as a result of both the reduction in working hours, and the slowdown of productivity growth per hour worked. For the Netherlands, therefore, higher levels employments rates went hand in hand with declining productivity growth.

Figure 2.6 Changes in the number of hours worked per person employed correlated with changes in productivity per hour (1995-2005)

Volumes, average annual percentage change



Source: calculations based on data from the EU KLEMS database (March 2008 update). Remarks: outliers Ireland and Italy were removed from the plot. * New Zealand and Canada share the same co-ordinate in the graph: (1.5; 0.7).

Although we do not find a direct visible cross-correlation between productivity growth and the change in the employment rate, Figure 2.6 shows that there appears to be a negative correlation between the change in the number of hours worked per person employed and the growth of productivity per hour. Recent empirical research confirms that productivity growth is negatively influenced by a rising utilisation of labour within the economy, in terms of both hours worked and the employment rate (see also Section 2.2.1 of this chapter and Chapter 9). Bourlès and Cette (2007) find evidence that 0.5 percentage points of US average annual productivity growth of 2.5 percent over the period 2000-2004 was attributable to a drop in the employment rate (average annual impact: 0.3 percentage points) and a decrease in hours worked (average annual impact: 0.2 percentage points).

2.3. AN ANALYSIS AT THE INDUSTRY LEVEL

2.3.1 Productivity level and growth in the Netherlands by industry

Table A.1 in the annex presents labour productivity levels by industry in the Netherlands for the years 1970, 1980, 1990, 2000 and 2005. Industries differ considerably in productivity performance, which follows largely from differences in capital intensity.[11] Labour productivity growth in the periods 1970-1980, 1980-1990, 1990-2000 and 2000-2005 is also included in Table A.1. Although growth in manufacturing from 1980s onwards was not as high as over the 1970s, up till 2005 productivity growth in manufacturing was quite stable around 3% on an annual basis. The services sector shows a much more volatile pattern. After realising high annual growth rates over the period 1970-1980, productivity growth in the total services sector slowed down to approximately 1.0 annually.

Productivity growth differs considerably between the underlying industries of the manufacturing and the services sector. Most industries show a steady rise of productivity levels over time. If we focus on manufacturing, throughout the 80s and 90s the industries *chemicals and chemical products* (24), *electrical and optical equipment* (30-33), and *transport equipment* (34-35) show an above average performance in productivity growth. After the turn of the century, *chemicals and chemical products* (24) outperformed all other manufacturing industries, both in terms of productivity levels (€ 104.8 per hour in 2005) and annual labour productivity growth (6.9% between 2000-2005), whilst the *electrical and optical equipment* industry (30-33) showed a severe drop in growth (-2.9% annually between 2000 and 2005). Within the services sector, productivity growth in *wholesale trade* (51), *communications* (64) and *financial intermediation* (65-67) exceeds the average growth in the total services sector in the entire period of observation. In contrast, productivity growth in *retail trade* (52), *hotels and restaurants* (55), *real estate* (70), *other business services* (74) and *community and social services* (75-99) showed negative growth or marginal growth at best throughout the 90s and beginning of the 21st century.

2.3.2 International benchmark

To put the productivity performance of Dutch industries into perspective, Figures 2.7 and 2.8 show where individual industries are ranked internationally on productivity levels and growth.[12] The performance of the Dutch industries is benchmarked with a weighted average of twenty OECD countries.[13] The magnitude of each industry in terms of employment is indicated in the

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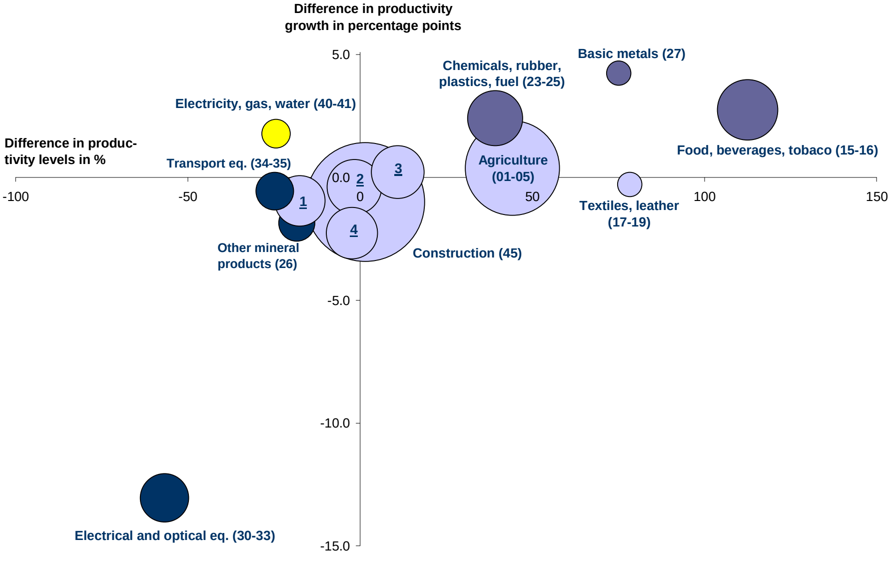
[11] The industries *mining and quarrying* and *real estate activities*, in particular, have high levels of productivity, because natural gas revenues and the rental value of personal residence are regarded as value added.

[12] In order to compare productivity levels of industries internationally, industry-specific purchasing power parities are required (see, for instance, Van Ark and Timmer, 2002). Commissioned by the Ministry of Economic Affairs, the Groningen Growth & Development Centre calculated the required industry-specific purchasing power parities (see Van Ark *et al.*, 2003).

[13] Productivity data at the industry level *per hour worked* are calculated for twenty OECD countries: Australia, Austria, Belgium, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Japan, the Netherlands, Portugal, Spain, Sweden, the UK and the US. The Netherlands is compared

figures by the size of each circle. Figure 2.7 illustrates the productivity performance of Dutch manufacturing and other non-services industries in an international context. Subsequently, Figure 2.8 shows an international comparison of the productivity performance of Dutch services industries. In general, the productivity level of Dutch manufacturing is 6% higher than the OECD average, but the growth is slightly lower (-0.7 percentage points).

Figure 2.7 International comparison of productivity levels (2005) and growth (2000-2005) at the industry level; NL vis-à-vis OECD average, manufacturing and other non-services industries



Source: Figures A.1.1 and A.2.2 in the annex. 1: *machinery and eq.* (29), 2: *paper and publishing* (21-22), 3: *fabricated metals* (28), 4: *other manufacturing* (36-37). ISIC codes in brackets. *Mining and quarrying* (10-14) is not visible in the graph (productivity levels difference: 948, productivity growth difference: 6.5, hours worked: 15 million). The industry descriptions are abbreviated in both Figures A.1.1 and A.1.2. The ISIC (Rev. 3) codes in brackets correspond with the ISIC codes in Table A.1, which can be used to derive the full description of each industry.

The manufacturing industries *chemicals, rubber, plastics and fuel* (23-25), *basic metals* (27) and *food, beverages and tobacco* (15-16) have a strong international position: productivity levels are higher than those of foreign peers and productivity is growing more rapidly as well in these

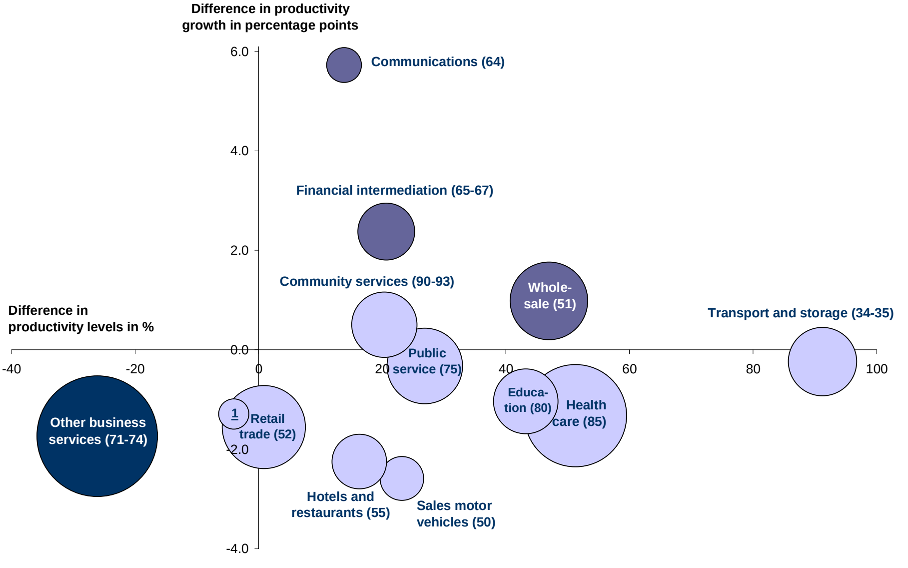
with a weighted average of these countries. Since the average productivity growth in these countries together was roughly equal to the total OECD average, they constitute an adequate benchmark for assessing Dutch productivity performance.

industries. Figure 2.7 also shows that the sector *electricity, gas and water supply* (40-41) is quickly catching up to international levels of productivity.

At the other end of the spectrum, manufacturing industries such as *transport equipment* (34-35) and *other non-metallic mineral products* (26) are lagging behind the international average both in terms of productivity levels and growth. More striking in this context, however, is the position of the Dutch *electrical and optical equipment* (30-33). To some extent, the poor performance of the *electrical and optical equipment industry* can be attributed to statistical shortcomings, which complicate a valid international comparison of productivity performance in this sector. One of these statistical predicaments is addressed by Minne and Van der Wiel (2004). The Dutch electrical and optical equipment industry is characterised by a considerable number of large multinational companies, including Philips, Océ, ASML, Neways Electronics, and ASMI. Although the Netherlands is home to large headquarters and R&D facilities of these companies, manufacturing is mainly conducted abroad. Statistical offices, however, primarily register output in the countries where the factories of the multinationals are established, and not in the headquarters and laboratories. The consequence of this measurement methodology is that the contribution of managers and researchers to production and productivity growth of Dutch multinationals in the electrical and optical equipment industry is largely registered as being foreign growth. The performance of the Dutch electrical and optical equipment industry is therefore underestimated and would improve if the productivity contribution of business units other than manufacturing divisions were accounted for in national statistics. The specific composition of the electrical and optical equipment industry in comparison with other countries is also visible in the large share of services in gross production. Nearly fifty percent (45% to be exact) of the value of production generated by the electrical and optical equipment industry can be attributed to services activities (Statistics Netherlands, 2008, Table G 1.1). The measurement of productivity developments of these services is interspersed with statistical drawbacks, which complicates a realistic international comparison even further. Despite the above-mentioned statistical drawbacks, however, the productivity performance of the Dutch electrical and optical equipment industry remains questionable (Minne and Van der Wiel, 2004, p. 66). We will return to this matter in more detail in Section 2.4.3.

Figure 2.8 shows that services industries encompasses a much more important source of employment compared to manufacturing, i.e. most circles in Figures 2.8 have a larger diameter than in Figure 2.7. As to the productivity performance, although the productivity level of many services industries lies above the international average, these industries risk losing this strong productivity position due to a shortfall in productivity growth.

Figure 2.8 International comparison of productivity levels (2005) and growth (2000-2005) at the industry level; NL vis-à-vis OECD average, services industries



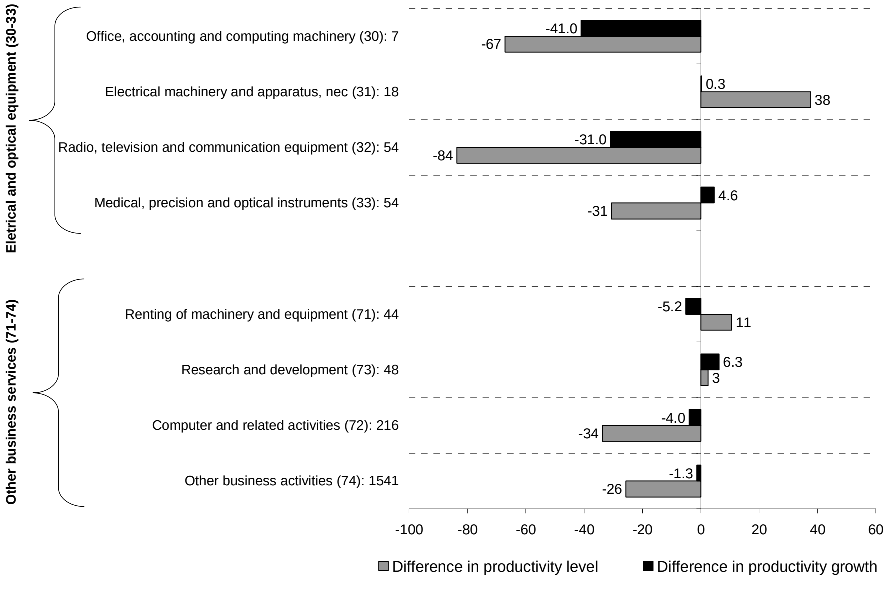
Source: Figures A.1.1 and A.2.2 in the annex. 1: *real estate activities* (70). ISIC codes in brackets. The industry descriptions are abbreviated in both Figures A.1.1 and A.1.2. The ISIC (Rev. 3) codes in brackets correspond with the ISIC codes in Table A.1, which can be used to derive the full description of each industry.

This is especially the case for *retail trade* (51), *hotels and restaurants* (55), *sales of motor vehicles and fuel*, (50), *health care* (85) and *education* (80). In addition to a lower growth rate of productivity than abroad, *retail trade* (52) and especially *other business services* (71-74) show a shortfall in productivity levels as well. Services industries that are expanding their already strong productivity performance are *wholesale* (51), *financial intermediation* (65-67) and particularly *post and telecommunications* (64).

In Figures 2.7 and 2.8, the industries *electrical and optical equipment* and *other business services* stand out due to a substantial lower level and growth of productivity compared to the international average. However, both sectors consist of four sub-industries each, which show diversity in productivity performance as well (see Figure 2.9). Apart from *electrical machinery and apparatus, nec* (31) each sub-industry of the *electrical and optical equipment* reveals lower than average productivity levels. In addition, productivity growth in *office, accounting and computing machinery* (30) and *radio, television and communication equipment* (32) lags behind the international average to a considerable extent. However, as said, the weak position of the electrical and optical equipment industry remains arguable due to measurement problems.

Within the *other business services* sector, the two largest sectors in terms of employment (*computer and related activities* (72) and *other business activities* (73)) fall short on both productivity levels and growth when compared with abroad.

Figure 2.9 International productivity performance in sub-sectors of the electrical and optical equipment industry and other business services



Explanation: employment in millions of hours is shown after the colon of each sub-sector.

Source: calculations based on data from the EU KLEMS database (March 2008); industry-specific purchasing power parities taken from Van Ark *et al.* (2003).

2.3.3 International shift-share analysis

An analysis at the industry level is also relevant in order to identify the extent to which various industries contribute to productivity growth at the national economy level, and how possible differences in industry composition (developments) relate to macro productivity. A shift-share analysis is the appropriate methodology for this. By means of this analysis, it is possible to distinguish between productivity growth *within* industries and shifts in employment *across* industries. The contribution of a separate industry is divided into three components (see, for instance, Scarpetta *et al.*, 2000; Van Ark and De Haan, 2000; and Van der Wiel, 1999):

1. Each sector contributes directly to productivity growth at the aggregate level. This contribution is referred to as the '*intra-sectoral effect*'. The intra-sectoral effect is calculated

by multiplying labour productivity growth within an industry by the share of this industry in the value added of the total economy.

2. The effect of shifting employment shares is known as the *'net-shift effect'*, and is also referred to as the *'shift-share effect'*. The labour productivity growth of the total economy (aggregate) rises when the employment share increases of an industry with a higher than average labour productivity level.
3. Finally, there is a residual effect, the *'interaction effect'*. This effect is positive when industries with growing labour productivity have a growing employment share within the economy or when industries with a falling labour productivity decline in relative size.

The equation to conduct the shift-share analysis can be derived as follows. Labour productivity (Y/L) at the macro level is approximately equal to the sum of the volume of value added in each separate industry (Y_i), divided by the usage of labour in the total economy (L).[14] For the industries 1…n – an individual industry is denoted by i – we can write:

$$\frac{Y}{L} = \frac{\sum_{i=1}^{n} Y_i}{L} = \sum_{i=1}^{n} \frac{Y_i}{L} = \sum_{i=1}^{n}\left(\frac{Y_i}{L_i} \times \frac{L_i}{L}\right) \tag{2.1}$$

If labour productivity is expressed as a percentage change, we can derive from (2.1):

$$\begin{aligned}\overset{\bullet}{\left(\frac{Y}{L}\right)} &= \sum_{i=1}^{n}\left(\left(\frac{\frac{Y_i}{L_i}\times\frac{L_i}{L}}{\frac{Y}{L}}\right)_{t=0} \times \overset{\bullet}{\left(\frac{Y_i}{L_i}\times\frac{L_i}{L}\right)}\right) = \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \overset{\bullet}{\left(\frac{Y_i}{L_i}\times\frac{L_i}{L}\right)}\right) \\ &= \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\overset{\bullet}{\left(\frac{Y_i}{L_i}\right)} + \overset{\bullet}{\left(\frac{L_i}{L}\right)} + \overset{\bullet}{\left(\frac{Y_i}{L_i}\right)} \times \overset{\bullet}{\left(\frac{L_i}{L}\right)} \times \frac{1}{100}\right)\right)\end{aligned} \tag{2.2}$$

[14] Volumes of value added at the industry level (expressed in price levels of a certain base year) add up to the volume of value added at the macro level if the growth rates of volumes of value added at the industry level are aggregated using fixed weights. The fixed weights express the shares of individual industries in nominal value added at the aggregate level in the base year for the price deflator (where volumes of value added are equal to the nominal values). An alternative method is to use *current weights*. In that case the weights are determined by using the shares of individual industries in nominal value added at the aggregate level in the previous year. For more information about both methodologies, see Tuke and Reed (2001). In the EU KLEMS database a more advanced method is used, based on the Törnqvist index. In this approach weights are calculated as unweighted averages of the shares in nominal value added in the preceding and the current year (see, e.g., Dumagan, 2002). In equations (2.1)-(2.5), on which the shift-share analysis in this paper is based, aggregation of volumes of value added is conducted using the fixed weights methodology. This implies that aggregate labour productivity growth in the shift-share analysis deviates somewhat from aggregate labour productivity growth in the EU KLEMS database. For the sake of simplicity we accept this minor difference. The base year for the price deflator in our shift-share analysis is 2005, which means that the fixed weights represent shares in nominal value added in 2005.

The index t = 0 denotes the base year ('year 0') of the shift-share analysis (which is 2005 in the calculations presented in this chapter). Equation (2.2) can be rewritten as follows:

$$\left(\frac{\dot{Y}}{L}\right) = \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{Y_i}}{L_i}\right)\right) + \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{L_i}}{L}\right)\right)$$
$$+ \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{Y_i}}{L_i}\right) \times \left(\frac{\dot{L_i}}{L}\right) \times \frac{1}{100}\right) \tag{2.3}$$

The first term at the right hand side of the equation (2.3) represents the intra-sectoral effect. The third term represents the interaction effect. The net-shift effect can be derived from the second term:

$$\left(\frac{\dot{Y}}{L}\right) = \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{Y_i}}{L_i}\right)\right) + \sum_{i=1}^{n}\left(\left(\frac{Y_i}{L_i} \Big/ \frac{Y}{L}\right)_{t=0} \times \Delta \frac{L_i}{L} \times 100\right)$$
$$+ \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{Y_i}}{L_i}\right) \times \left(\frac{\dot{L_i}}{L}\right) \times \frac{1}{100}\right) \tag{2.4}$$

The second term at the right-hand side of equation (2.4) shows the impact of a change in the employment share of an industry $\Delta(L_i/L)$ on labour productivity growth, which depends on the level of labour productivity in this industry relative to the average macro level (Y_i/L_i relative to Y/L). Because the relative level of labour productivity in an industry is by definition larger than zero, an increase in the employment share of a certain industry would inevitably result in a positive contribution to labour productivity growth at the macro level, whereas a decrease in the employment share of an industry would result in a negative contribution to macro productivity growth. To obviate this problem, the term representing relative labour productivity levels is rewritten to express the relative deviation of the productivity level of an industry from the average macro level. This can be executed by simply subtracting 1.0 from the productivity level of an industry relative to the average macro level:

$$\left(\frac{\dot{Y}}{L}\right) = \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{Y_i}}{L_i}\right)\right) + \sum_{i=1}^{n}\left(\left(\frac{Y_i}{L_i}\Big/\frac{Y}{L} - 1\right)_{t=0} \times \Delta\frac{L_i}{L} \times 100\right)$$
$$+ \sum_{i=1}^{n}\left(\left(\frac{Y_i}{Y}\right)_{t=0} \times \left(\frac{\dot{Y_i}}{L_i}\right) \times \left(\frac{\dot{L_i}}{L}\right) \times \frac{1}{100}\right) \tag{2.5}$$

The subtraction of 1.0 in the relative productivity expression does not have any influence on macro summation, because at the macro level this figure is multiplied by the sum of the absolute changes of employment shares of the industries. These absolute changes, of course, add up to zero. The subtraction of 1.0 is only functional to validly represent the contributions of the net-shift effects at the industry level.

Intra-sectoral effect

In the Netherlands, as well as an average of twenty OECD countries (hereinafter: OECD), the positive productivity growth observed at the macro level in the period 1995-2005 can be mainly attributed to *intra-sectoral effects* across various industries (see Table A.2 in the annex).[15] The cumulated intra-sectoral effect in the Netherlands constitutes 18.9% and in the OECD this effect is only 1 percentage point higher (19.9%). Although the difference of the intra-sectoral effect between the Netherlands and the OECD on the macro level is limited, the divergence between certain industries is much larger. Within manufacturing the Dutch *electrical and optical equipment* industry (30-33) has a relatively small intra-sectoral effect, whereas the industry *chemicals and chemical products* (24) performs better than abroad.[16] Within the total services sector the intra-sectoral effect was higher than in the OECD, due to relatively large intra-sectoral effects of *wholesale trade* (50), *transport and storage* (60-63) and *financial intermediation* (65-67). In contrast, *retail trade* (52) and *health and social work* (85) in the Netherlands realised intra-sectoral effects which were 0.8 percentage points below the international average.

[15] The cumulated growth rates of productivity over the period 1995-2005 in the Netherlands and the OECD of 15.9% and 19.5% respectively are in line with the computed annual growth rates of productivity in Figure 2.4 of 1.6% and 2.0%. There are small deviations, which are due to different methods for the aggregation of volumes of value added (see the previous footnote).

[16] The intra-sectoral effect within the *electrical and optical equipment industry* (30-33) in the Netherlands amounts to 0.3 percentage points, whereas abroad this contribution is 2.4 percentage points. The Dutch *radio, television and communication equipment* industry (32) in particular shows a large intra-sectoral shortfall of 1.4 percentage points compared with the international OECD average. As a consequence, the total electrical and optical equipment industry in the OECD contributes roughly 10% to macro productivity growth, whereas in the Netherlands this contribution is somewhat less than 3%.

Net-shift effect

The *overall net-shift effect* in the Netherlands in the period 1995-2005 amounts to -1.0 percentage points, whereas the OECD shows a positive contribution of 1.3 percentage points. This means that employment in the Netherlands shifted towards industries that have a lower than average productivity level, whereas in the OECD the opposite occurred. The difference in net-shift effects between the Netherlands and the OECD of 2.3 percentage points is the main reason behind the total productivity growth discrepancy of 3.6 percentage points (19.5% versus 15.9%). The total negative net-shift effect in the Netherlands is caused first and foremost by employment shifts towards the business services sector *other business activities* (74) and a declining *mining and quarrying* industry (10-14). In the Netherlands the employment share of *other business activities* (74) increased quite heavily between 1995 and 2005 from 11.4% to 13.4%. This employment shift resulted in a relatively large negative net-shift effect, because productivity of the sector *other business activities* is below the average productivity level in the Netherlands (see Table A.1). As for Dutch *mining and quarrying* (10-14), the decrease in employment as such was fairly small. Moreover, the productivity level of this sector is exceptionally high compared with the Dutch average (again see Table A.1). As a consequence, it only takes a marginal drop of employment to result in a relatively large negative net-shift effect. In the OECD an employment shift towards *real estate* (70) and a decline of employment in the low-productive agricultural (01-05) sector generated the largest positive net-effects (1.1 and 0.9 percentage points correspondingly).

Interaction effect

In the Netherlands as well as in the other OECD countries the *interaction effect* contributes negatively to macro productivity growth (-2.1 and -1.7 percentage points respectively). In the OECD, this negative effect is the result of declining employment shares of the *electrical and optical equipment industry* (30-33) in combination with rapidly growing productivity in this sector (11.4% annually between 1995-2005). In the Netherlands, the total negative interaction effect consists of numerous smaller interaction effects in various industries, such as *chemicals and chemical products* (24), *electricity, gas and water supply* (40-41) and *wholesale trade* (51).

2.3.4 Do differences in sector composition matter?

The shift-share analysis conducted in Section 2.3.3 showed that employment shifts between industries are the main explanation behind the Dutch comparatively lower macro productivity growth vis-à-vis the OECD (in the period 1995-2005). Additional analysis in this section, however, will show that this does not imply that the Dutch *sector composition* obstructs productivity growth. The impact of the Dutch industry composition on macroeconomic productivity development is analysed by comparing actual effects from the shift-share analysis for the Netherlands (see Table A.2) with ‘hypothetical’ effects from an alternative shift-share analysis. These hypothetical effects are determined by conducting a ‘hypothetical’ shift-share analysis for the Netherlands under the assumption that both the sector composition in 1995 and the development of Dutch employment shares in the period 1995-2005 were equal to the international average.[17]

In Table A.3 the impact of the Dutch sector composition on labour productivity growth in the Netherlands is demonstrated. The results point out that the Dutch sector composition does not contribute negatively to Dutch productivity growth. Quite the opposite: the Dutch sector composition has a positive impact on productivity development in the Netherlands. The overall effect of the Dutch sector composition is 1.6%, which means that the Dutch sector composition generates 1.6 percentage points higher productivity growth than would have been the case if the Netherlands had a similar sector composition as the OECD. The positive impact of the Dutch sector composition is the result of relatively large positive intra-sectoral effects in the industries *wholesale trade* (51), *transport and storage* (60-63) and *financial intermediation* (65-67). These three industries are responsible for almost 50% of the overall productivity growth in the Netherlands during 1995-2005 (see Table A.3). The strong position of the Netherlands in these industries is also visible in Figure 2.8. As the share of these industries in total value added is smaller in the OECD (the Netherlands in 2005: 25.7%; OECD in 2005: 16.7%), the contribution of these relatively high-productive industries in the Netherlands would have been much smaller if the Dutch sector composition had equalled that of the OECD. Furthermore, in this hypothetical situation, employment shifts would turn out unfavourably with regard to the *mining and quarrying* industry (10-14). In this highly productive Dutch sector the employment reduction abroad over the period 1995-2005 was twice as high as in the Netherlands.

2.4 EXPLAINING PRODUCTIVITY PATTERNS

2.4.1 Growth accounting methodology

The growth accounting methodology provides a useful tool to determine to what extent labour productivity growth is the result of changes in factor inputs (per hour worked), and thereby to delineate total factor productivity (TFP) growth. The first growth accounting exercises were conducted by Tinbergen (1942), although they were noticed internationally only much later (see Griliches, 2000, pp. 9-11). Starting point of the growth accounting exercise is a simple production function, where gross value added (*Y*) is a function of capital (*K*) and labour (*L*) inputs:

$$Y = f(K, L) \tag{2.6}$$

[17] In order to conduct the ‘hypothetical’ shift-share analysis for the Netherlands, ‘hypothetical’ value added shares of each industry within total economy were derived. This was done by linking the international average employment share of each individual industry within the total economy to the Dutch labour productivity level of that individual sector.

Assuming competitive product and factor markets and constant returns to scale, equation (2.6) can be reformulated as follows:

$$\Delta \ln Y = v_k \Delta \ln K + v_l \Delta \ln L + \Delta \ln A \qquad (2.7)$$

In equation (2.7) v_k and v_l denote the input shares of capital and labour respectively in gross value added. 'Δ ln' refers to the first difference of the natural logarithm of a variable, which is (in case of small changes) approximately equal to the growth rate of that variable. $\Delta \ln A$ represents the rise in gross value added over the growth in weighted factor inputs, or total factor productivity (TFP) growth. TFP is arguably the purest indicator of productivity, since it represents the residual disembodied technological change within an economy. TFP growth is calculated as a residue, by attributing the share of capital deepening to labour productivity growth.

The capital component in equation (2.7) can be broken down into contributions of ICT capital (K^{ict}) and non-ICT capital ($K^{n\text{-}ict}$). ICT capital consists of office and computer machinery, communications equipment and software. Non-ICT capital includes other machinery, transport equipment and non-residential structures (see Timmer *et al.*, 2003). Including ICT capital as separate capital component changes equation (2.7) into:

$$\Delta \ln Y = v_{k^{ict}} \Delta \ln K^{ict} + v_{k^{n-ict}} \Delta \ln K^{n-ict} + v_l \Delta \ln L + \Delta \ln A \qquad (2.8)$$

Equation (2.8) does not distinguish between the contribution of different types of labour, e.g. low-skilled labour versus high-skilled labour, to value added growth. The contribution of composition changes of labour inputs is usually referred to as the contribution of human capital (per unit of labour) or labour quality growth and can be calculated as a separate component within the growth accounting methodology (see, for instance, Benhabib and Spiegel, 1994; Sørensen and Whitta-Jacobsen, 2005, p. 150; Jorgenson *et al.*, 2005). We define labour inputs (L) as the contribution of 'labour services', which allows for differences in the amount of services delivered per unit of labour in the growth accounting approach (see Timmer *et al.*, 2007):

$$\Delta \ln L = \Delta \ln H + \Delta \ln LC \qquad (2.9)$$

In equation (2.9) the change of labour services is broken down into a component measuring the change in hours worked (H) and a component measuring the change in labour composition (LC). The benefit of 'labour composition change' in comparison with other human capital indicators (e.g. average duration of education of the working-age population or the share of higher educated labour within the labour force) is that it does not imply that workers with lower wages have a lower quality. A positive labour composition change implies a shift towards workers with higher wages and hence, higher marginal productivity (see Inklaar *et al.*, 2006). In the EU KLEMS database labour composition is measured by distinguishing three skill levels of persons employed: low-skilled, medium-skilled and high-skilled labour.[18]

Substituting (2.9) into (2.8) leads to the following equation for value added growth:

$$\Delta \ln Y = v_{k^{ict}} \Delta \ln K^{ict} + v_{k^{n-ict}} \Delta \ln K^{n-ict} + v_l (\Delta \ln H + \Delta \ln LC) + \Delta \ln A \tag{2.10}$$

As we assume constant returns to scale ($v_{k^{ict}} + v_{k^{n-ict}} + v_l = 1$), equation (2.10) can be rewritten in terms of growth in *average labour productivity* (see also Jorgenson and Stiroh, 2000):

$$\begin{aligned} \Delta \ln Y - \Delta \ln H = {} & v_{k^{ict}} (\Delta \ln k^{ict} - \Delta \ln H) + v_{k^{n-ict}} (\Delta \ln k^{n-ict} - \Delta \ln H) \\ & + v_l \Delta \ln LC + \Delta \ln A \end{aligned} \tag{2.11}$$

Equation (2.11) decomposes labour productivity growth, measured as the (natural logarithmic) change of gross value added per hour worked ($\Delta\ln Y - \Delta\ln H$) into four elements. First, the term ($\Delta\ln k^{ict} - \Delta\ln H$) is referred to as *ICT capital deepening* and represents the contribution of ICT capital services in relation to hours worked. The second term ($\Delta\ln k^{n\text{-}ict} - \Delta\ln H$) is *capital deepening from non-ICT* and denotes the contribution of non-ICT capital services per hour worked. 'Capital services' refer to the services flows from different types of physical capital.[19] Thirdly, the term ($\Delta\ln LC$) measures the contribution of labour composition change. The fourth and final element ($\Delta\ln A$) in equation (2.11) is the contribution of *total factor productivity* (TFP) growth and is determined as a residual within the growth accounting framework.

2.4.2 Decomposition of labour productivity growth at the macro level

Equation (2.11) is used to decompose labour productivity growth per hour worked in the total economy for a selection of OECD countries (see Table 2.2). Growth in two periods, viz. 1995-2000 and 2000-2005, is considered. Data to conduct the decomposition is taken from the EU KLEMS database. Because the EU KLEMS database only presents decomposition figures of value added, we calculated decomposition figures of productivity growth ourselves.

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18 For more information on the measurement of labour composition we refer to Timmer *et al*. (2007, p. 6).

19 To calculate the contribution of ICT capital and non-ICT capital to economic growth, the EU KLEMS database uses the definition of *capital services* instead of *capital stocks*, because capital services measure the consumption of capital more accurately. Within the definition of capital services, a differentiation is made between the economic life span of different types of capital. The shorter the life expectancy of a certain capital good, the greater the contribution to production capacity. Capital goods with a short life expectancy have a higher rate of depreciation. As a consequence, the costs have to be recovered over a shorter period of time. Within the definition of capital services, therefore, capital goods with a short economic life span have a larger appraisal within the total capital stock compared with capital with a longer life expectancy.

Table 2.2 Decomposition of labour productivity growth per hour worked, 1995-2005

Labour productivity growth: average annual percentage change; contribution of various components in percentage points

	1995-2000					2000-2005				
	LP	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**
Australia	2.4	0.4	0.8	0.2	1.0	1.4	0.6	0.8	0.3	-0.3
Austria	2.1	0.3	0.6	0.3	0.9	0.9	0.1	0.3	0.2	0.3
Belgium	1.2	0.4	0.9	0.3	-0.3	1.1	0.5	0.6	0.2	-0.2
Denmark	1.0	-0.1	1.0	0.3	-0.3	1.1	0.3	0.6	0.2	-0.1
Finland	2.7	0.0	0.5	0.2	2.0	1.8	0.2	0.4	0.3	0.9
France	2.0	0.3	0.3	0.5	0.8	1.4	0.6	0.2	0.3	0.4
Germany	2.0	0.9	0.5	-0.1	0.6	1.4	0.7	0.3	0.1	0.3
Ireland	4.6	1.7	0.6	0.5	1.8	3.1	2.4	0.1	0.6	-0.1
Italy	0.8	0.3	0.3	0.2	-0.1	-0.1	0.5	0.1	0.2	-0.9
Japan	2.5	1.4	0.5	0.5	0.2	2.4	1.3	0.4	0.4	0.4
Luxembourg	1.1	0.2	0.5	0.8	-0.3	0.5	0.0	0.5	0.2	-0.1
Netherlands	1.6	0.2	0.7	0.2	0.5	1.6	0.3	0.3	0.5	0.4
Portugal	2.5	1.7	0.9	-0.4	0.3	0.5	1.1	0.5	0.9	-1.9
Spain	0.1	0.1	0.4	0.4	-0.8	0.6	0.7	0.2	0.5	-0.8
Sweden	2.5	1.0	0.6	0.2	0.6	2.7	0.9	0.3	0.3	1.2
UK	2.2	0.5	0.9	0.5	0.3	1.6	0.3	0.5	0.4	0.4
US	2.0	0.4	1.0	0.2	0.4	2.5	0.6	0.5	0.2	1.2
EU15*	1.5	0.4	0.5	0.2	0.3	1.1	0.5	0.3	0.2	0.1

* Weighted average of the following ten EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain and the UK.

Explanation: LP = growth of value added per hour worked; ICT = contribution of ICT capital deepening; Non-ICT = contribution of non-ICT capital deepening; LC = contribution of labour composition change; TFP = contribution of total factor productivity growth. Labour productivity growth in percentage changes and the contributions of the various components in percentage points were approximated by means of first differences of natural logarithms, which is in accordance with the growth accounting approach in the EU KLEMS database.

Source: calculations based on data from EU KLEMS database (March 2008 update).

The decomposition in Table 2.2 shows that many countries experienced a higher overall productivity growth in the period 1995-2000 compared to 2000-2005. The decrease in growth can be attributed to two effects. First, ICT capital deepening played a less prominent role as a source of productivity growth after the turn of the century. In each country the contribution of ICT capital deepening in 2000-2005 was lower than in the preceding period. Second, TFP growth slowed down considerably in many countries or even contributed negatively. Especially the Mediterranean countries Italy, Spain and Portugal reveal a large negative contribution of total factor productivity growth in the period 2000-2005. In contrast, countries that continued to realise high productivity growth figures after 2000 demonstrate high growth rates of total factor productivity as well, e.g. Finland, Sweden, the US and to a lesser extent the UK and the Netherlands.[20]

The US in particular shows a much faster overall productivity growth due to high growth of TFP. Between 2000 and 2005, average TFP growth in the US was 1.2% annually, whereas in the EU15 TFP contributed a marginal 0.1% on average in that period. Van Ark *et al.* (2008, p. 35) draw the same conclusion: *"the main difference in labour productivity growth between individual European countries and the United States is to be found in multifactor productivity, not in differences in the intensity of the production factors"*. Jorgenson *et al.* (2008) also confirm that from 2000 onwards TFP growth has been the most important source of private output growth in the US.

A closer look at the situation in the Netherlands learns that the decomposition analysis is roughly identical in the two periods considered, with two exceptions. First, as in other countries, the contribution of ICT capital in 2000-2005 was lower than in 1995-2000. Second, the contribution of labour composition change rose noticeably from 0.2 percentage points annually in 1995-2000 to 0.5 percentage points annually in 2000-2005. The effect of non-ICT capital deepening was relatively modest by European standards over the entire period of observation. The modest contribution of non-ICT capital deepening is related to strong employment growth in the period 1995-2000. This had a negative effect on the growth of the capital-labour ratio through the denominator of this ratio (Donselaar *et al.*, 2003; Ederveen *et al.*, 2005). Another possible impact of higher employment growth on overall productivity growth, which is channelled through TFP growth, is the increase of the share of low-paid labour in total employment (Pomp, 1998; Belorgey *et al.*, 2006). However, this overall suppressing effect on TFP was relatively modest in the Netherlands (see Donselaar *et al.*, 2003; Ederveen *et al.*, 2005).

[20] Ireland and Japan also managed high labour productivity growth between 2000 and 2005, but this was caused by a large contribution of non-ICT capital deepening.

2.4.3 Decomposition of labour productivity growth at the industry level

The data available in the EU KLEMS database also opens up possibilities to conduct international decompositions of labour productivity growth at the industry level. Table A.4 and Table A.5 in the annex show decomposition exercises of Dutch sectoral productivity growth over the periods 1995-2000 and 2000-2005 respectively. The Dutch sectoral decomposition in both tables is compared with a decomposition of the US and a weighted average of ten EU15 countries.

A comparison between the growth decompositions in Table A.4 and Table A.5 reveals that the absolute contribution of ICT capital deepening in almost all industries in the Netherlands, the EU15 and the US was lower in the period 2000-2005 compared to the period 1995-2000. This observation is in accordance with the macro decomposition analysis in the previous section. The lower contribution of ICT capital deepening in the latter period is most prominent in *financial intermediation* (Netherlands: -1.2 percentage points; US: -1.6 percentage) and in *post and telecommunications* (EU15: -1.7 percentage points; US: -2.3 percentage points).[21] The contribution of labour composition change to sectoral productivity growth kept reasonably stable in both periods of observation. In contrast, the contribution of non-ICT capital deepening and total factor productivity shows much volatility, but a clear pattern does not emerge.

For the analysis of the productivity decomposition for individual industries we concentrate on the most recent period, i.e. 2000-2005 (Table A.5 in the annex). Most remarkable is the weak performance of the *electrical and optical equipment industry* (30-33) in the Netherlands, especially in comparison with productivity growth of this sector in the US. The US experienced a much faster pace of TFP growth in the *electrical and optical equipment industry*, which resulted in a labour productivity growth difference compared with the Netherlands of almost 15 percentage points on an annual basis in 2000-2005. As already addressed in Section 2.3.2, the low productivity performance of the Dutch electrical and optical equipment industry can, to some extent, be attributed to statistical drawbacks. However, there are also indications that the weak productivity position of this sector is not solely due to statistical problems (see Minne and Van der Wiel, 2004, p. 66). First of all, the sector serves markets with moderately poor growth rates. Secondly, the Dutch electrical and optical equipment industry produces a low rate of new and significantly improved products. Third, the demand for ICT products within the Dutch market seems to fall short, which complicates fully exploiting the advantages of economies of scale. Statistics Netherlands confirms that the Dutch electrical and optical equipment industry might be backing the wrong horse. First, the high share of services in gross production of the electrical and optical equipment industry in the Netherlands puts pressure on productivity, as these services have a lower productivity development than the manufacturing of good. In addition, the ICT-producing part of the electrical and optical equipment industry mainly

[21] These figures illustrate differences of the contribution of ICT capital deepening to productivity growth between the two periods 1995-2000 and 2000-2005, expressed in percentage points.

fabricates office machinery and equipment, which are characterised by lower productivity development than other ICT equipment (i.e. computers).

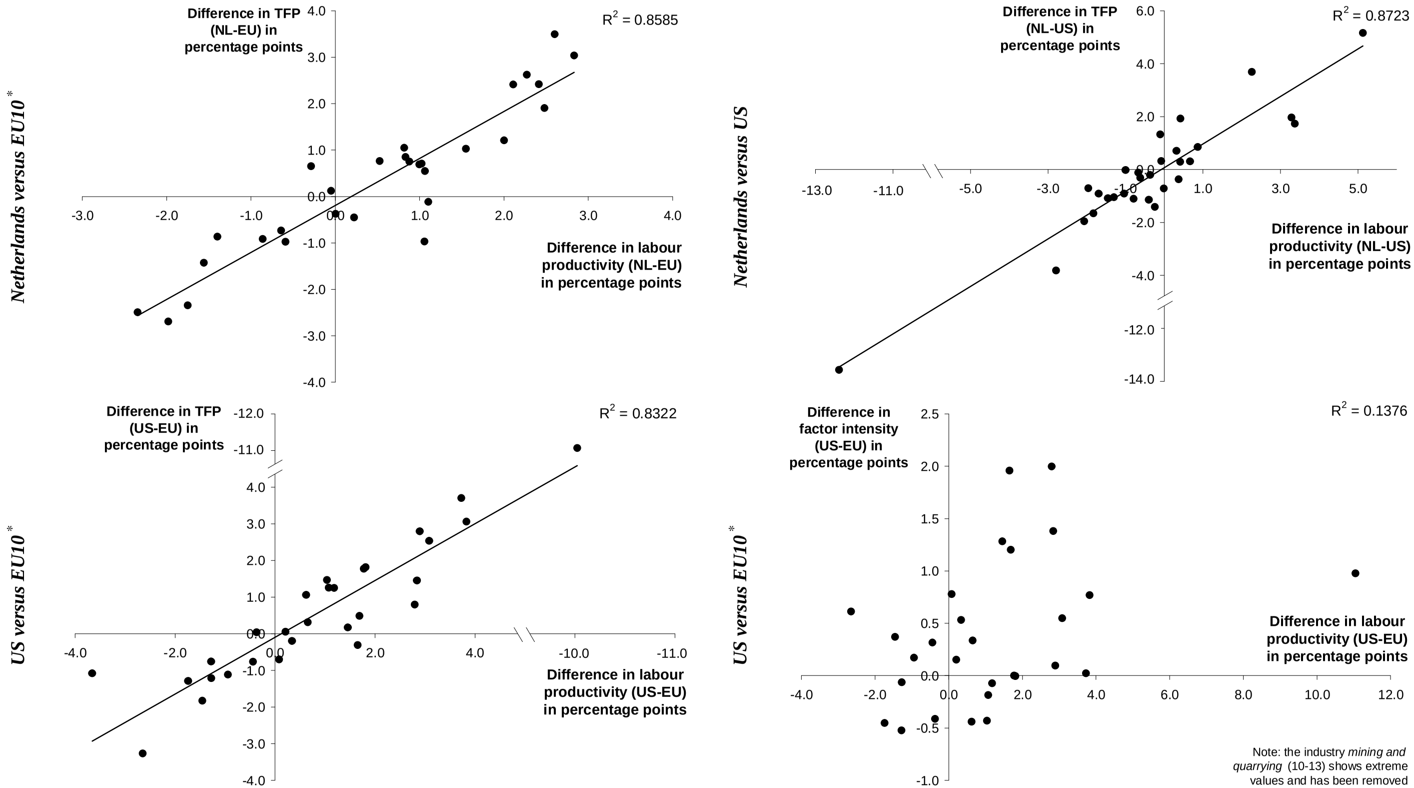
Dutch productivity growth in the industry *post and telecommunications* (64) outpaced the EU15 and the US to a substantial degree, principally due to a high growth of total factor productivity. Other industries that perform well are *financial intermediation* (65-67), *food, beverages and tobacco* (15-16), *chemicals and chemical products* (24) and *wholesale trade* (51). The high growth performance of these industries cannot be ascribed to large investments in physical or human capital, but is primarily related to a high TFP performance (although non-ICT capital in *food, beverages and tobacco* was also considerable by international standards). Reversely, the same pattern is visible: US industries that manifestly outperform European industries in productivity growth show a large contribution of the TFP component in particular. This is especially the case in *textiles, leather and footwear* (17-19), *other manufacturing* (36-37), *sales and repairs of motor vehicles* (50), *retail trade* (52) and *other business services* (71-74).

More in general, TFP growth discrepancies provide the key explanation for differences in productivity growth performance between the Netherlands, the EU and the US at the industry level. This is illustrated by the correlation diagrams in Figure 2.10, based on Table A.4 and A.5 in the annex. There is a clear positive correlation between sectoral growth differences in labour productivity and sectoral growth differences in total factor productivity. The R^2 is very high indicating that sectoral growth differences in total labour productivity can almost completely be attributed to differences in TFP growth differences. The plot in the bottom-right corner shows the correlation between sectoral productivity growth differences and differences in the contribution of factors inputs (i.e. ICT, non-ICT and labour composition change) in the US vis-à-vis the EU. This correlation is weak, which proves that sectoral growth differences in productivity are only marginally explained by differences in intensity of physical and human capital.

Interestingly, TFP growth in the non-market sectors *public administration* (75), *education* (80) and *health care* (85) in both the US and the EU countries is low or negative. Particularly the negative TFP growth in these sectors in the Netherlands is remarkable. However, it is not recommended to draw strong conclusions from this, because productivity performance is difficult to measure in these public sectors. Information provided by Statistics Netherlands reveals that independent sources are used for estimates of productivity development in the health sector and in primary and secondary education. For tertiary education and other parts of the government such independent information is not available. It is therefore not possible for Statistics Netherlands to measure productivity growth in (tertiary and total) education and in other government sectors adequately, as is described in a recent publication on ‘growth accounts’ (including productivity measurement) of Statistics Netherlands (2007).

Figuur 2.10 Correlation between sectoral growth differences in labour productivity and total factor productivity, 1995-2005

Difference in average annual growth mutations are expressed in percentage points



* Weighted average of the following ten EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain and the UK. Remarks: the plot in the bottom-right corner illustrates a correlation between the sectoral growth differences in labour productivity and a combined average of the contribution of factor inputs, e.g. ICT capital, non-ICT capital and labour composition change (see also Tables A.4 and A.5). Source: calculations based on data from the EU KLEMS database (March 2008 update).

The results from our decomposition analysis are in correspondence with a recent study by Maudos *et al*. (2008). The authors performed a shift-share analysis (analogous to the analysis in Section 2.3.3) to examine the productivity slowdown of the EU15 vis-à-vis the US since the mid-90s. Their results show that the difference in the intrasectoral effect is the main cause behind the growing productivity gap between the US and the EU15. In other words; the slowdown in growth in the EU15 is above-all caused by modest 'pure' gains of productivity *within* European industries and is not due to sectoral re-allocation of employment. This result is in accordance with the observed productivity divergences between the European and US' industries in our analysis (Table A.4 and Table A.5). However, our growth accounting exercise goes one step further, as it enables us to pinpoint the reasons behind the modest intrasectoral effect within European sectors when compared to the US. As mentioned, differences in sectoral productivity performance between the Netherlands, the EU and the US cannot be attributed to large divergences in investments in physical or human capital, but are especially related to differences in total factor productivity (see Figure 2.10). This observation raises the question as to what exactly determines growth of total factor productivity. There are indications that high TFP growth in especially the US' services industries in the most recent years can possibly be explained by a much better utilisation of ICT in these industries compared to the Netherlands and the EU countries in general. This, in turn, could be related to a better performance of the US on other drivers of productivity growth, such as competition, entrepreneurship and innovation (including non-technological innovation), which are complementary factors for a more productive use of ICT (e.g. Buijink, 2007; Timmer, 2007; Van Ark and Inklaar, 2005; Van Ark, 2007). In the remainder of this thesis (especially Chapter 3 and 9), the drivers of total factor productivity are examined more methodically.

2.5 CONCLUSIONS AND POLICY IMPLICATIONS

This chapter discusses Dutch productivity performance on a macro and industry level compared with other countries and attempts to identify more general productivity trends. As to the Netherlands, productivity levels per hour worked still rank among the highest in the OECD. Productivity growth dropped in the beginning of the 90s, but picked up again from 1995 onwards. The Dutch productivity growth figure, however, lies below that of the OECD and the US. The US in particular managed to speed up productivity growth in the 21st century proceeding from levels of productivity and participation that were already high. In contrast, the EU15 shows a systematic decrease of productivity growth over the entire period of observation (1970-2005).

In the 1990s, the slowdown of productivity growth in the Netherlands was related to high employment growth over the last decade, resulting in high levels of participation (see Donselaar *et al*., 2004). The shift-share analysis in this chapter learns that for a more recent period (1995-2005) the annual gap in productivity growth of 0.4 percentage points compared to the OECD average is largely related to employments shifts towards less than average productive sectors in the Netherlands (e.g. *other business activities* (74)) and an increase of the employment share towards more productive sectors abroad.

When focussing on the determinants of productivity growth, most noticeably the impact of ICT capital deepening on productivity growth in almost each sector and OECD country has declined over time. Instead, countries that maintained fast growth of productivity in the 21st century are characterised by a high growth rate of total factor productivity as well (Finland, Sweden and especially the US)[22], whereas countries that show below-average productivity growth realised poor TFP growth figures (e.g. Italy, Spain, Portugal and the EU15 in general). On a sectoral level it also becomes clear that the international productivity position is largely determined by divergences in TFP growth.[23]

We conclude this chapter with five observations for discussion, which may be relevant for policy. Our general conclusion is that, although the Netherlands as well as other OECD countries faces challenges in terms of future productivity growth, these challenges are not necessarily identical or monotonous.

Productivity and ageing

Clearly one of the main challenges regarding productivity growth is related to population ageing in OECD countries. Ageing will reduce the potential workforce (Table 2.3) and will raise the dependency ratio. Since future economic growth will depend on the sum of employment growth and productivity growth, it is clear that boosting productivity will be high on the agenda for all countries.

As an illustration, if productivity growth per hour in the EU were to proceed as in the second half of the 1990s, assuming a growth rate of the capital stock of 2% and a participation rate of 57.9%, growth of GDP per capita would amount to less than 1.5% per year. This is 0.5 percentage points below the EU average for the period 1950-1998 (Bosman, 2003). Ageing, therefore, not only stresses the need for further improvements in participation, but also puts high on the agenda the question as to what extent the other pillar of economic growth – productivity – can be strengthened in order to mitigate negative effects on future prosperity.

22 Japan and Ireland realised high growth of productivity due to a large contribution of non-capital deepening.

23 There is a new strand of literature which takes growth accounting a step further: see Corrado *et al.* (2005, 2006). This literature treats any use of resources that reduces current consumption in order to increase future consumption as investments. The spending on these ‘intangibles’ include R&D, copyrights, films, computerised databases, brand equity, etc. It is questionable, however, whether investments in intangibles, such as R&D activities, can be treated as direct capital components within the growth accounting framework, because the social returns on knowledge-related activities are higher than private returns, which complicates the quantification of the price and quantity components. Nevertheless, this topic definitely deserves more examination and taking account of intangibles in international growth accounting exercises would be an important topic for future research.

However, for several reasons discussed in this chapter, this challenge may vary in both urgency and content. As Table 2.3 shows, there are substantial differences in expected demographic developments in OECD countries. This demographic differentiation – in combination with varying degrees of macro- and microeconomic preparedness for such changes – of course means that the urgency of increasing productivity also varies.

Table 2.3 Working-age population in selected EU countries (in millions), 2000-2050

Country	Working age population 2000	Working age population 2050
EU15	252.14	209.72
Netherlands	10.81	10.59
Germany	55.80	44.14
France	38.87	35.88
Italy	38.88	26.07

Source: Eurostat.

Productivity and participation

Besides dissimilar demographic trends between counties, there is also considerable differentiation in performance between countries on both productivity growth and levels on the one hand and participation on the other hand (see Table 2.1 in Section 2.1.1). In particular, the possible interplay between them is important. Countries with relatively low levels of participation (either hours worked or people engaged) often show higher productivity levels. Clearly, for these countries the challenge regarding future growth (and also ageing) lies particularly in raising labour market participation. However, it is possible that such a rise in participation might be accompanied by a negative impact on productivity growth (at least in the short term).[24] The policy challenge in terms of productivity will thereby consist of countering negative productivity effects from rising participation. Europe as a whole, with a few exceptions, is lagging behind in productivity (growth), when compared with the other side of the Atlantic, and in the number of hours worked. Each member state will have to adjust its institutional setting to realise the combined productivity and participation targets. For such policymaking to be effective, a better insight into the drivers of productivity growth is required.

Moving the productivity frontier

Experience in the United States has shown that even from a starting point of high productivity levels, further increases in productivity are possible. For other countries – such as the Netherlands – this could imply that high initial levels of productivity do not rule out the possibility of further improvement. However, the challenge here is not one of catching up. It is also one of moving the productivity frontier. This chapter shows that possibilities to shift the

[24] The negative impact of higher participation in terms of people engaged is due to the growth in employment of less productive labour. In the case of a greater number of hours worked per person employed, fatigue aspects can have a downward impact on productivity growth.

productivity frontier should not be discussed on the macro level, but primarily on the industry level or even lower levels of aggregation. In other words, whereas some industries in the Netherlands perform much better in productivity levels than those in other countries, others clearly do not. The problem at stake, however, might be more complicated than that. Also *within* industries the distribution of productivity performance is far from identical. Research by Van Ark *et al.* (2004) shows that in virtually all industries, the top quartile of productive firms in the US is more productive than its European (and Dutch) counterparts. Furthermore, this top quartile in the US is gaining market share while this is much less the case in Europe.

The dilemma for policymakers in this respect is complex. Beyond any doubt the explanation behind the superior US performance lies to a large extent in differences in framework conditions and the working of markets. Better functioning of markets for labour, capital and products provide the incentives for top of the bill performance and contribute to and enable reallocation of resources within an economy towards its most productive use. But on the other hand, policymakers are faced with differences and specifics, not simply in performance but possibly also in the nature of underlying market imperfections at the industry level. Doing justice to differences in the nature of productivity requires a delicate mix of generic and specific policy stances.

TFP ≠ ICT

This paper shows that in recent years TFP has been the main component of high productivity growth in countries. The *new economy* hypothesis postulated that accelerating labour productivity growth *and* TFP growth could be attributed to ICT. However, this paper offers a number of suggestions that this is not so straightforward. First, TFP growth frequently followed a rise in investment in ICT with a certain time lag. This at least implies that possible beneficial effects of ICT only materialised with a lag, possibly due to accompanying adjustments in firms that enabled a boost of TFP. Second, a number of fast-growing countries in terms of labour productivity and TFP did not witness substantial investment in ICT. Clearly this suggests that ICT is not likely to be the unique source of TFP development. This observation is in accordance with Van Ark (2006), who concludes that ICT does *not* earn ‘supra-normal’ returns, suggesting there is no evidence of spillovers from ICT investment, at least not at the industry level. Finally and closely related to the second argument, on an industry level not all sectors that have invested heavily in ICT, experienced strong TFP growth, and interestingly, the TFP performance in similar sectors in different countries varies substantially, even if ICT investments did prevail. Whereas for services, ICT and TFP appear to be somehow related (see last paragraph of Section 2.4.3) – also other explanatory factors play a role here – for manufacturing there clearly is not such a relationship. These suggestions lead to the conclusion that ICT most likely played a role in the acceleration of TFP growth, but that this relation is far from omnipresent and that other factors (innovation, organisational change, framework conditions, entrepreneurship, etc.) are perhaps more important for TFP.

Industry level revisited
Understanding productivity patterns and underlying effects, as well as policy implications requires analysis on a lower level of aggregation. This encompasses different dimensions (including, for instance, productivity performance at the local level related to the possibility of optimal internalisation of agglomeration effects), but first and foremost the industry level.

This chapter yields a number of interesting results in this respect. First, the chapter shows that differences in (changes in) the sector composition of the Dutch economy, as compared with the economies of other countries, only plays a minor role in explaining international differences in Dutch productivity performance. Therefore, it is unlikely that the sector composition of the Dutch economy is an important obstacle for further future growth. In addition, whereas a decomposition analysis at the macro level shows that TFP patterns play a more decisive role in explaining productivity differentials than differences in (the quality of) of input factors, the decomposition analysis on a lower level of aggregation (i.e. the industry level) enables to identify in which segments of the economy TFP differentials are most outstanding.

Second, looking at the industries where Dutch (and frequently European) productivity performance is lagging behind (e.g., *other business services*, *electrical and optical equipment*), or is above average (e.g. *food, chemicals*, *basic metals, financial intermediation, post and telecommunications*), the question is: what does it mean? Sound economics would suggest that this mainly reflects comparative advantages and that it is largely irrelevant for policy. An alternative interpretation, however, is that the Netherlands’ productive strength is more manifest in – for the sake of a better word – ‘traditional’ industries, whereas in ‘new’ industries the track record is less positive. Or to put it another way: is the Netherlands missing the boat in areas (i.e. sectors) where future economic growth can be expected? The below-average performance in some services sectors in the Netherlands could be a case in point.

Underperformance of ‘new’ industries and lagging TFP growth are probably linked. The US’ productivity success is not so much related to a higher use of ICT capital per se, but rather to a more productive utilisation of such capital in a relatively small number of industries. The below-average performance of such industries in the Netherlands in combination with disappointing TFP figures at least provides food for thought for further analysis, both at industry and micro level. In our view this food for thought should also be on policymakers’ plates as well.

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ANNEX

Table A.1 Levels and growth of labour productivity at the industry level, the Netherlands; 1970-2005

Levels: price level of 2005, in euros; growth: average annual percentage change

		Levels					Growth			
	ISIC rev. 3	**1970**	**1980**	**1990**	**2000**	**2005**	**1970-1980**	**1980-1990**	**1990-2000**	**2000-2005**
Agriculture, hunting, forestry and fishing	01-05	4	7	11	13	15	6.9	5.4	1.0	3.5
Mining and quarrying	10-14	77	1,177	763	762	890	31.4	-4.2	0.0	3.1
Total manufacturing	15-37	10	18	25	34	40	5.9	3.3	3.2	3.1
Food products, beverages and tobacco	15-16	16	26	35	48	57	5.2	3.0	3.1	3.8
Textiles, textile products, leather and footwear	17-19	11	20	26	39	43	6.2	3.0	4.0	1.9
Wood and products of wood and cork	20	2	5	6	7	7	6.5	2.7	1.6	0.7
Pulp, paper and paper products	21	8	14	21	27	34	6.3	4.0	2.5	4.7
Printing and publishing	22	9	16	23	31	34	6.0	3.3	3.3	1.6
Coke, ref. petroleum products and nuclear fuel	23	114	342	180	170	205	11.6	-6.2	-0.6	3.8
Chemicals and chemical products	24	17	30	45	75	105	6.0	4.1	5.2	6.9
Rubber and plastics products	25	8	16	26	30	34	6.9	5.0	1.4	2.5
Other non-metallic mineral products	26	10	19	24	22	24	6.5	2.3	-0.9	1.6
Basic metals	27	29	48	51	68	93	5.2	0.8	2.8	6.6
Fabricated metal products (except M&EQ)	28	8	16	24	30	34	6.6	4.2	2.6	2.0
Machinery and equipment, n.e.c.	29	8	14	21	28	32	5.2	4.0	3.0	3.0
Electrical and optical equipment	30-33	6	9	13	27	23	5.2	3.8	7.4	-2.9
Transport equipment	34-35	7	11	17	32	38	3.7	4.9	6.6	3.1
Manufacturing n.e.c., recycling	36-37	10	19	25	26	27	6.5	2.6	0.2	1.2
Electricity, gas and water supply	40-41	28	59	72	90	120	7.6	2.1	2.3	5.9
Construction	45	20	23	29	26	25	1.3	2.3	-1.0	-0.7
Wholesale and retail trade, repairs	50-52	12	17	22	28	31	3.6	2.8	2.5	2.5
Sale, repair of motor vehicles; sale of fuel	50	15	20	25	29	30	3.1	2.0	1.8	0.2
Wholesale trade and commission trade	51	13	19	25	35	44	3.4	2.8	3.7	4.4
Retail trade	52	9	13	17	18	18	4.2	2.7	0.3	0.6

Table A.1 (continued)

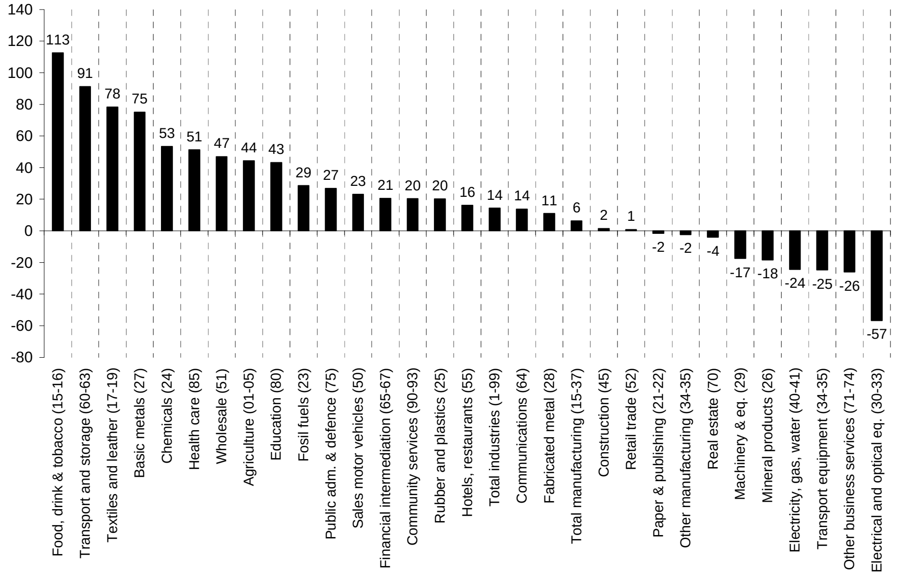
		Levels					Growth			
	ISIC rev. 3	**1970**	**1980**	**1990**	**2000**	**2005**	**1970-1980**	**1980-1990**	**1990-2000**	**2000-2005**
Hotels and restaurants	55	14	20	19	19	17	3.4	-0.5	0.2	-1.9
Transport, storage and communications	60-64	23	31	41	55	70	3.0	2.6	3.1	4.8
Transport and storage	60-63	34	45	55	67	73	2.8	2.1	2.0	1.7
Communications	64	10	15	22	37	67	3.6	4.2	5.5	12.3
Finance, insurance, real estate and business services	65-74	33	46	47	46	50	3.4	0.3	-0.2	1.4
Financial intermediation	65-67	35	48	63	71	90	3.3	2.7	1.2	4.9
Real estate activities	70	165	154	280	285	280	-0.7	6.2	0.2	-0.3
Renting of machinery and equipment	71	36	77	77	89	87	8.0	0.0	1.5	-0.6
Computer and related activities	72	11	22	23	28	30	7.0	0.4	2.0	1.2
Research and development	73	32	49	40	29	35	4.2	-1.9	-3.4	4.2
Other business activities	74	20	27	24	24	24	3.2	-1.3	0.1	-0.2
Community, social and personal services	75-99	26	34	35	35	35	2.9	0.1	0.0	0.0
Public administration and defence; compulsory social security	75	22	30	37	44	47	3.3	2.2	1.7	1.1
Education	80	36	43	44	43	41	1.7	0.2	-0.1	-1.3
Health and social work	85	25	33	34	33	32	2.5	0.3	-0.3	-0.7
Other community, social and personal services	90-93	39	52	29	26	27	3.1	-5.8	-1.0	1.1
Private households with employed persons	95	13	14	7	7	8	1.0	-7.1	0.2	1.5
Total services[*]	50-99	23	31	35	39	41	3.3	1.4	0.9	1.0
Grand total	01-99	18	27	32	36	39	4.4	1.7	1.2	1.6

[*] Volume mutations of the total services sector were aggregated using the Törnqvist index (see, e.g., Dumagan, 2002). Data series of total services start from 1971 instead of 1970.

Source: calculations based on data from the EU KLEMS database (March 2008 update); industry-specific purchasing power parities taken from Van Ark *et al.* (2003).

Figure A.1.1 Levels of labour productivity per hour worked at the industry level, the Netherlands compared with an average of twenty OECD countries*, 2005

Difference between the Netherlands and the foreign average in percentages



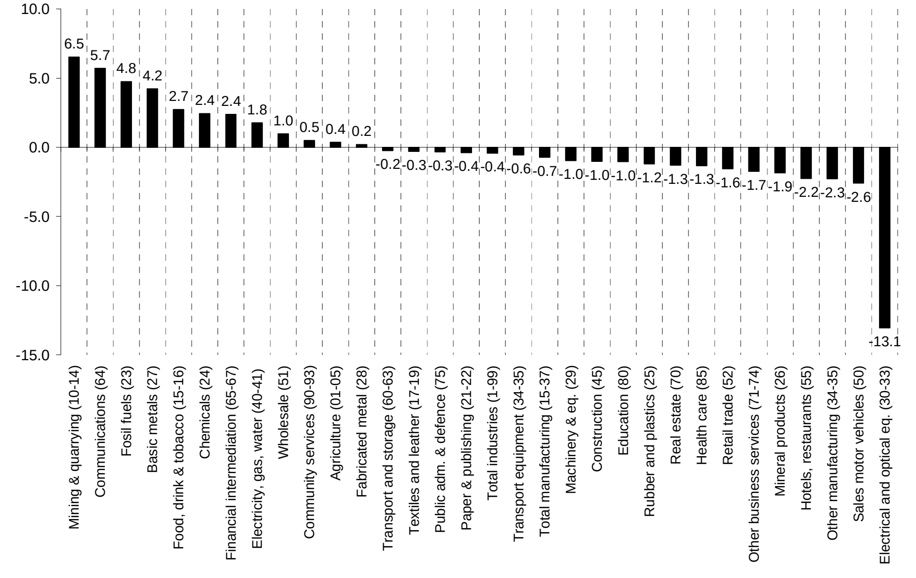
* The Netherlands compared with a weighted average of the following countries: Australia, Austria, Belgium, the Czech Republic, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Japan, the Netherlands, Portugal, Spain, Sweden, the UK and the US. The industry 'mining and quarrying' is not shown (value: 948).

The industry descriptions are abbreviated in both Figures A.1.1 and A.1.2. The ISIC (Rev. 3) codes in brackets correspond with the ISIC codes in Table A.1, which can be used to derive the full description of each industry.

Source: calculations based on data from EU KLEMS (March 2008 update); industry-specific purchasing power parities taken from Van Ark *et al.* (2003).

Figure A.1.2 Annual growth of labour productivity per hour worked at the industry level, the Netherlands compared with an average of twenty OECD countries*, 2000-2005

Difference between the Netherlands and the foreign average in percentage points



* The Netherlands compared with a weighted average of the following countries: Australia, Austria, Belgium, the Czech Republic, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Japan, the Netherlands, Portugal, Spain, Sweden, the UK and the US.

The industry descriptions are abbreviated in both Figures A.1.1 and A.1.2. The ISIC (Rev. 3) codes in brackets correspond with the ISIC codes in Table A.1, which can be used to derive the full description of each industry.

Source: calculations based on data from the EU KLEMS database (March 2008 update); industry-specific purchasing power parities taken from Van Ark *et al.* (2003).

Table A.2 Shift-share analysis for the Netherlands and an average of 20 OECD countries[*]; total economy, 1995-2005

Cumulated total effects over 1995-2005; contribution of the various components in percentage points

		The Netherlands					20 OECD countries				
	ISIC rev. 3	Total	Intra-sectoral effect	Net-shift effect	Inter-action effect	% of macro growth	Total	Intra-sectoral effect	Net-shift effect	Inter-action effect	% of macro growth
Agriculture, hunting, forestry and fishing	01-05	0.5	0.3	0.3	0.0	3.4	1.4	0.7	0.9	-0.2	7.1
Mining and quarrying	10-14	-0.5	0.4	-0.8	-0.1	-2.9	-0.2	-0.1	-0.1	0.0	-1.1
Total manufacturing[**]	15-37	4.4	5.5	0.2	-1.2	28.0	5.5	6.7	0.3	-1.5	28.5
Food products, beverages and tobacco	15-16	0.6	1.0	-0.2	-0.3	3.5	0.1	0.1	0.0	0.0	0.5
Textiles, textile products, leather and footwear	17-19	0.2	0.2	0.0	-0.1	1.0	0.4	0.3	0.3	-0.1	2.2
Wood and products of wood and cork	20	0.1	0.0	0.1	0.0	0.5	0.1	0.1	0.0	0.0	0.5
Pulp, paper and paper products	21	0.1	0.1	0.0	0.0	0.9	0.1	0.2	0.0	-0.1	0.7
Printing and publishing	22	0.4	0.4	0.1	-0.1	2.3	0.2	0.2	0.0	0.0	1.0
Coke, refined petroleum products and nuclear fuel	23	-0.1	0.0	-0.1	0.0	-0.6	-0.1	0.1	-0.1	0.0	-0.4
Chemicals and chemical products	24	1.1	1.6	-0.2	-0.3	6.8	0.5	0.7	-0.1	-0.1	2.5
Rubber and plastics products	25	0.1	0.1	0.0	0.0	0.7	0.3	0.3	0.0	0.0	1.4
Other non-metallic mineral products	26	0.1	0.1	0.0	0.0	0.5	0.2	0.2	0.0	0.0	1.0
Basic metals	27	0.2	0.4	-0.1	-0.1	1.5	0.1	0.3	-0.1	-0.1	0.5
Fabricated metal products (except M&EQ)	28	0.3	0.3	0.0	0.0	1.6	0.3	0.3	0.0	0.0	1.6
Machinery and equipment, n.e.c.	29	0.4	0.4	0.0	0.0	2.3	0.5	0.6	0.0	-0.1	2.6
Electrical and optical equipment	30-33	0.5	0.3	0.2	-0.1	2.8	1.9	2.4	0.2	-0.7	9.6
Office machinery	30	0.0	0.0	0.0	0.0	0.1	0.4	0.6	0.1	-0.2	2.2
Electrical machinery and apparatus n.e.c.	31	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	-0.1	0.8
Radio, television and communication eq.	32	0.1	0.0	0.1	0.0	0.6	1.1	1.4	0.1	-0.4	5.9
Medical, precision and optical instruments	33	0.3	0.3	0.1	-0.1	2.1	0.1	0.2	0.0	0.0	0.7
Transport equipment	34-35	0.4	0.4	0.1	-0.1	2.4	0.6	0.8	0.0	-0.1	3.3
Manufacturing n.e.c., recycling	36-37	0.3	0.2	0.1	0.0	1.7	0.3	0.3	0.0	0.0	1.4
Electricity, gas and water supply	40-41	0.2	0.8	-0.3	-0.3	1.6	0.6	1.3	-0.4	-0.3	2.9
Construction	45	-0.4	-0.3	0.0	0.0	-2.5	0.0	0.0	0.0	0.0	0.0

Table A.2 (continued)

		The Netherlands					20 OECD countries				
	ISIC rev. 3	**Total**	**Intra-sectoral effect**	**Net-shift effect**	**Inter-action effect**	**% of macro growth**	**Total**	**Intra-sectoral effect**	**Net-shift effect**	**Inter-action effect**	**% of macro growth**
Wholesale and retail trade**	50-52	4.8	4.9	0.3	-0.3	30.4	3.8	3.7	0.3	-0.2	19.4
Sale, repair of motor vehicles; sale of fuel	50	0.6	0.6	0.1	0.0	3.7	0.5	0.5	0.0	0.0	2.8
Wholesale trade and commission trade	51	3.6	3.8	0.1	-0.3	22.8	1.9	1.9	0.1	-0.2	9.6
Retail trade	52	0.6	0.5	0.1	0.0	3.9	1.4	1.3	0.1	0.0	7.0
Hotels and restaurants	55	0.2	0.1	0.1	0.0	1.0	0.0	0.2	-0.2	0.0	0.0
Transport, storage and communications**	60-64	4.0	4.0	0.0	0.0	25.1	2.4	2.5	0.0	-0.2	12.1
Transport and storage	60-63	2.3	2.4	0.0	-0.1	14.2	1.0	1.0	0.0	-0.1	5.0
Communications	64	1.7	1.7	0.0	0.1	10.9	1.4	1.5	0.0	-0.1	7.1
Finance, insurance, real estate and business services**	65-74	2.5	3.0	-0.7	0.3	16.0	5.4	3.4	1.3	0.6	27.5
Financial intermediation	65-67	2.0	2.0	-0.1	0.0	12.4	1.1	1.2	-0.1	0.0	5.6
Real estate activities	70	0.7	0.5	0.2	0.0	4.5	2.1	0.9	1.1	0.1	10.9
Renting machinery & eq./other business activities	71-74	-0.1	0.5	-0.8	0.2	-0.9	2.1	1.3	0.3	0.5	11.0
Renting of machinery and equipment	71	0.2	0.1	0.1	0.0	1.3	0.4	0.3	0.0	0.1	2.2
Computer and related activities	72	0.1	0.2	-0.3	0.2	0.5	0.8	0.4	0.1	0.3	4.2
Research and development	73	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Other business activities	74	-0.4	0.2	-0.6	0.0	-2.7	0.9	0.6	0.1	0.2	4.6
Community, social and personal services**	75-99	0.0	0.3	0.0	-0.3	-0.2	0.7	1.3	-0.6	0.0	3.6
Public admin., defence; compulsory social security	75	1.1	1.4	-0.2	-0.1	6.8	0.9	1.0	-0.1	-0.1	4.7
Education	80	-0.7	-0.7	0.1	0.0	-4.4	-0.2	-0.2	0.0	0.0	-0.9
Health and social work	85	-0.8	-0.6	0.0	-0.2	-4.8	-0.2	0.2	-0.4	0.0	-1.1
Other community, social and personal services	90-93	0.2	0.2	0.0	0.0	1.4	0.3	0.3	0.0	0.0	1.5
Private households with employed persons	95	0.1	0.1	0.1	0.0	0.8	-0.1	0.0	-0.1	0.0	-0.6
Total services**	50-99	11.5	12.3	-0.3	-0.4	72.4	12.2	11.2	0.8	0.2	62.6
Grand total**	01-99	15.9	18.9	-1.0	-2.1	100.0	19.5	19.9	1.3	-1.7	100.0

* Weighted average of the following 20 OECD countries: Australia, Austria, Belgium, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Japan, the Netherlands, Portugal, Spain, Sweden, the UK and the US. ** Main aggregates were calculated by adding up from a lower level of aggregation. Consequently, the intra-sectoral effect on a higher level of aggregation represents the sum of intra-sectoral effects of industries on a lower level of aggregation. This way, the intra-sectoral effect is adjusted for effects of changes in employment shares of these sub-industries within the main aggregates. Effects of changes in employment shares are expressed in the net-shift effects and interaction effects on higher levels of aggregation.

Source: calculations based on data from the EU KLEMS database (March 2008 update).

Table A.3 Effect of Dutch sector composition (compared with the average sector composition of 20 OECD countries[*]) on labour productivity growth in the Netherlands, total economy, 1995-2005

Cumulated effects over the period 1995-2005; contributions in percentage points

	ISIC rev. 3	Total	Intra-sectoral effect	Net-shift effect	Inter-action effect
Agriculture, hunting, forestry and fishing	01-05	-0.3	0.1	-0.4	0.0
Mining and quarrying	10-14	0.1	-0.6	0.6	0.1
Total manufacturing	15-37	-0.7	-0.4	-0.2	-0.1
Food products, beverages and tobacco	15-16	0.0	0.3	-0.2	-0.2
Textiles, textile products, leather and footwear	17-19	-0.3	-0.5	-0.1	0.2
Wood and products of wood and cork	20	0.0	0.0	0.0	0.0
Pulp, paper and paper products	21	0.0	0.0	0.0	0.0
Printing and publishing	22	0.1	0.1	0.1	-0.1
Coke, refined petroleum products and nuclear fuel	23	0.1	0.0	0.1	0.0
Chemicals and chemical products	24	0.2	0.4	-0.1	-0.1
Rubber and plastics products	25	-0.1	-0.1	0.0	0.0
Other non-metallic mineral products	26	0.0	0.0	0.0	0.0
Basic metals	27	-0.1	-0.2	0.0	0.1
Fabricated metal products (except M&EQ)	28	0.0	0.0	0.0	0.0
Machinery and equipment, n.e.c.	29	-0.1	-0.1	-0.1	0.0
Electrical and optical equipment	30-33	0.0	0.0	0.1	0.0
Transport equipment	34-35	-0.4	-0.4	0.0	0.0
Manufacturing n.e.c., recycling	36-37	0.1	0.1	0.0	0.0
Electricity, gas and water supply	40-41	-0.2	0.0	-0.1	-0.1
Construction	45	0.0	0.0	0.0	0.0
Wholesale and retail trade	50-52	1.4	1.5	0.1	-0.1
Sale, repair of motor vehicles; sale of fuel	50	0.1	0.0	0.1	0.0
Wholesale trade and commission trade	51	1.4	1.5	0.0	-0.1
Retail trade	52	0.0	0.0	0.0	0.0
Hotels and restaurants	55	0.2	0.0	0.3	0.0
Transport, storage and communications	60-64	0.7	0.8	-0.2	0.1
Transport and storage	60-63	0.6	0.9	-0.1	-0.1
Communications	64	0.1	-0.1	0.0	0.2
Finance, insurance, real estate and business services	65-74	0.1	0.7	-0.6	0.0
Financial intermediation	65-67	0.8	0.6	0.2	0.0
Real estate activities	70	-0.7	0.0	-0.7	0.0
Renting machinery & eq./other business activities	71-74	0.0	0.1	-0.1	0.1
Community, social and personal services	75-99	0.2	0.3	0.0	-0.1
Public admin., defence; compulsory social security	75	0.0	0.2	-0.1	-0.1
Education	80	0.0	0.1	-0.1	0.1
Health and social work	85	-0.2	-0.2	0.0	-0.1
Other community, social and personal services	90-93	0.2	0.1	0.0	0.0
Private households with employed persons	95	0.2	0.0	0.2	0.0
Total services	50-99	2.6	3.2	-0.5	-0.1
Grand total	01-99	1.6	2.4	-0.5	-0.3

[*] Weighted average of the following 20 OECD countries: Australia, Austria, Belgium, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Japan, the Netherlands, Portugal, Spain, Sweden, the UK and the US.

Source: calculations based on data from the EU KLEMS database (March 2008 update).

Table A.4 Decomposition of labour productivity growth at the industry level, 1995-2000

Labour productivity growth: average annual percentage changes; contributions of various components in percentage points

		Netherlands					10 EU countries*					US				
	ISIC rev. 3	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**
Agriculture, hunting, forestry and fishing	01-05	-1.0	0.2	0.2	0.7	-2.1	4.3	0.8	0.0	0.3	3.2	4.8	0.0	0.1	0.0	4.7
Mining and quarrying	10-14	-1.0	1.0	0.4	0.4	-2.9	2.9	2.9	0.2	0.1	-0.4	0.5	0.9	0.7	-0.3	-0.8
Total manufacturing	15-37	3.2	0.4	0.5	0.3	2.1	2.3	0.6	0.4	0.2	1.0	4.5	0.5	0.9	0.4	2.6
Food, beverages and tobacco	15-16	1.7	0.6	0.5	0.3	0.3	0.6	0.4	0.3	0.4	-0.5	-2.5	-0.6	0.5	0.1	-2.6
Textiles, leather and footwear	17-19	6.0	0.8	0.5	0.4	4.4	2.0	1.0	0.3	0.4	0.3	3.5	1.3	0.4	0.6	1.2
Wood and products of wood and cork	20	1.0	0.9	0.5	0.4	-0.7	3.3	0.8	0.2	0.0	2.2	-0.7	-0.1	0.3	0.4	-1.3
Pulp, paper, paper products, printing and publishing	21-22	3.5	0.6	1.2	0.3	1.5	2.3	0.9	0.7	0.2	0.5	1.1	0.0	0.8	0.3	0.0
Coke, refined petroleum products and nuclear fuel	23	-4.3	0.8	-5.2	0.3	-0.3	0.0	1.3	0.1	0.2	-1.6	7.7	1.0	0.8	0.2	5.8
Chemicals and chemical products	24	4.5	1.4	0.2	0.2	2.6	1.8	0.8	0.5	-0.6	1.2	2.7	1.1	1.5	0.2	0.0
Rubber and plastics products	25	2.0	0.3	0.4	0.3	1.0	2.9	0.6	0.3	0.3	1.7	4.2	1.0	0.4	0.2	2.5
Other non-metallic mineral products	26	0.8	0.1	0.4	0.3	0.0	2.5	0.7	0.3	0.2	1.3	1.6	0.1	0.6	0.4	0.6
Basic metals and fabricated basic metal products	27-28	1.8	0.4	0.6	0.3	0.4	1.6	0.3	0.3	0.3	0.8	1.3	-0.3	0.4	0.3	0.8
Machinery and equipment, n.e.c.	29	3.5	0.3	0.9	0.4	1.9	1.4	0.3	0.4	0.2	0.4	1.4	1.3	1.7	0.2	-1.8
Electrical and optical equipment	30-33	8.0	0.2	1.4	0.4	5.9	5.7	0.6	0.8	0.1	4.2	18.7	1.0	1.3	0.4	16.0
Transport equipment	34-35	7.4	-1.5	0.5	0.3	8.1	1.8	0.3	0.3	0.1	1.1	2.2	0.7	0.9	0.6	-0.1
Manufacturing n.e.c., recycling	36-37	3.2	0.1	0.3	0.4	2.4	1.7	0.4	0.3	0.3	0.7	2.4	0.1	0.6	0.6	1.2
Electricity, gas and water supply	40-41	3.2	3.0	0.7	1.6	-2.1	5.8	2.8	0.5	0.2	2.4	3.0	1.8	0.7	0.2	0.3
Construction	45	-0.6	0.3	0.4	0.2	-1.5	-0.1	0.3	0.1	0.2	-0.9	-1.4	0.4	0.5	0.2	-2.4
Wholesale and retail trade	50-55	4.7	0.2	0.7	0.2	3.6	1.9	0.6	0.5	0.2	0.6	5.6	0.4	0.8	0.2	4.2
Sale, maintenance/repair motor vehicles; retail sale fuel	50	6.1	0.8	0.5	0.2	4.6	0.8	0.6	0.4	0.3	-0.5	5.2	0.7	0.7	0.3	3.6
Wholesale trade/commission trade, except motor veh.	51	5.9	0.0	0.9	0.2	4.8	2.6	0.6	0.8	-0.1	1.3	8.5	0.7	1.3	0.1	6.5

Table A.4 (continued)

		Netherlands					10 EU countries*					US				
	ISIC rev. 3	**LP**	**Non-ICT**	**ICT**	**HC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**HC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**HC**	**TFP**
Retail trade, except motor veh.; repair household goods	52	1.9	0.3	0.5	0.1	1.0	1.5	0.4	0.3	0.2	0.5	3.2	0.1	0.4	0.2	2.4
Hotels and restaurants	55	3.0	0.0	0.1	0.1	2.7	0.5	0.4	0.1	0.3	-0.3	1.1	0.1	0.2	0.1	0.7
Transport, storage and communications	60-64	5.1	0.8	0.9	0.3	3.1	5.0	0.4	1.2	0.1	3.2	2.1	0.1	2.7	0.3	-1.1
Transport and storage	60-63	2.9	0.0	0.5	0.2	2.2	2.7	0.4	0.5	0.2	1.6	1.4	-0.1	1.7	0.1	-0.3
Communications	64	8.7	2.3	1.1	0.1	5.1	9.7	0.6	2.6	0.1	6.3	2.8	0.3	3.7	0.1	-1.3
Finance, insurance, real estate and business services	65-74	-0.3	-0.6	1.0	0.2	-0.8	-0.7	-0.8	0.8	0.0	-0.6	0.8	0.0	1.5	0.2	-0.9
Financial intermediation	65-67	0.4	0.1	2.3	0.5	-2.6	2.8	0.4	1.4	0.3	0.7	3.5	0.8	2.5	0.5	-0.2
Real estate, renting and business activities	70-74	-0.3	-0.9	0.6	0.2	-0.3	-1.7	-1.6	0.7	0.1	-1.0	-0.2	-0.4	1.2	0.1	-1.1
Real estate activities	70	1.6	1.6	0.1	0.0	-0.2	-0.2	-0.4	0.1	0.0	0.0	0.8	0.9	0.1	0.0	-0.2
Renting of M&EQ and other business activities	71-74	1.2	0.2	1.0	0.4	-0.4	-0.2	0.2	1.3	0.2	-2.1	1.4	0.7	2.5	0.3	-2.1
Community, social and personal services	75-99	0.0	0.0	0.6	0.1	-0.7	0.3	0.2	0.3	0.2	-0.3	-0.2	0.3	0.4	0.1	-1.1
Public administration/defence; compulsory social security	75	1.9	0.4	0.9	0.3	0.2	1.3	0.3	0.3	0.4	0.3	0.3	0.6	0.5	0.3	-1.1
Education	80	-1.3	-0.2	0.8	0.1	-2.0	-0.5	0.0	0.1	0.4	-1.0	-0.2	0.2	0.6	0.2	-1.1
Health and social work	85	-0.7	-0.1	0.4	0.3	-1.3	0.9	0.2	0.2	0.4	0.0	-1.2	0.2	0.3	0.3	-2.1
Other community, social and personal services	90-93	0.5	0.0	0.5	-0.1	0.0	0.2	0.3	0.5	0.0	-0.5	1.6	0.1	0.2	0.4	0.9
Grand total	01-99	1.6	0.2	0.7	0.2	0.5	1.5	0.4	0.5	0.2	0.3	2.0	0.4	1.0	0.2	0.4

* Weighted average of the following ten EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain and the UK.

Explanation: LP = labour productivity growth (growth of value added per hour worked); ICT = contribution of ICT capital deepening; Non-ICT = contribution of non-ICT capital deepening; LC = contribution of labour composition change; TFP = contribution of total factor productivity growth. Labour productivity growth in percentage changes and the contributions of the various components in percentage points were approximated by means of first differences of natural logarithms, which is in accordance with the growth accounting approach in the EU KLEMS database.

Source: calculations based on data from the EU KLEMS database (March 2008 update).

Table A.5 Decomposition of productivity growth at the industry level, 2000-2005

Labour productivity growth: average annual percentage changes; contributions of various components in percentage points

		Netherlands					10 EU countries*					US				
	ISIC rev. 3	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**
Agriculture, hunting, forestry and fishing	01-05	3.4	0.2	0.1	2.0	1.1	1.6	0.8	0.0	0.3	0.5	3.3	1.1	0.1	0.1	2.0
Mining and quarrying	10-14	3.1	2.1	0.3	-0.1	0.9	-0.3	2.6	0.1	-0.1	-2.9	-5.2	-0.8	0.2	0.0	-4.6
Total manufacturing	15-37	3.0	0.7	0.1	0.7	1.5	2.3	0.7	0.2	0.5	0.9	5.4	0.9	0.5	0.5	3.5
Food, beverages and tobacco	15-16	3.7	1.4	0.3	0.5	1.5	0.9	0.4	0.2	0.4	-0.1	1.4	0.3	0.4	0.3	0.5
Textiles, leather and footwear	17-19	1.9	0.7	0.4	0.5	0.3	1.1	1.1	0.2	0.3	-0.4	5.8	1.4	0.3	0.4	3.8
Wood and products of wood and cork	20	0.7	0.8	0.1	0.9	-1.1	2.4	0.6	0.1	0.2	1.4	2.9	0.2	0.2	0.2	2.3
Pulp, paper, paper products, printing and publishing	21-22	2.3	0.7	0.3	0.9	0.4	1.6	0.8	0.4	0.4	0.0	4.0	0.7	0.5	0.3	2.6
Coke, refined petroleum products and nuclear fuel	23	3.7	-2.5	-5.8	0.3	11.7	-4.6	0.7	0.0	0.2	-5.5	3.5	1.4	1.0	0.1	0.9
Chemicals and chemical products	24	6.7	0.9	0.3	0.6	5.0	3.9	0.7	0.2	0.3	2.6	4.9	0.9	0.6	0.3	3.1
Rubber and plastics products	25	2.5	0.6	0.3	0.9	0.6	3.1	0.7	0.2	0.5	1.7	4.1	1.4	0.2	0.4	2.1
Other non-metallic mineral products	26	1.6	0.1	0.1	0.8	0.5	2.8	1.1	0.2	0.4	1.0	2.9	0.6	0.3	0.2	1.7
Basic metals and fabricated basic metal products	27-28	3.1	0.2	0.2	1.0	1.7	1.2	0.4	0.1	0.5	0.2	3.7	0.5	0.3	0.2	2.7
Machinery and equipment, n.e.c.	29	3.0	0.3	0.3	0.7	1.6	2.0	0.3	0.2	0.4	1.0	5.2	0.9	0.7	1.0	2.6
Electrical and optical equipment	30-33	-3.0	0.0	0.5	0.7	-4.2	4.0	0.6	0.4	0.4	2.5	13.1	0.6	0.4	1.2	10.8
Transport equipment	34-35	3.1	0.3	0.3	0.6	1.8	3.5	0.8	0.3	0.6	1.8	3.8	0.6	0.4	0.2	2.6
Manufacturing n.e.c., recycling	36-37	1.2	0.2	0.1	1.1	-0.3	1.0	0.7	0.3	0.3	-0.3	6.1	0.6	0.4	0.2	4.8
Electricity, gas and water supply	40-41	5.7	1.1	0.2	-0.6	5.1	4.3	1.5	0.3	0.0	2.6	4.2	2.6	0.6	0.1	1.0
Construction	45	-0.7	0.1	0.1	0.7	-1.6	0.6	0.7	0.1	0.1	-0.4	-0.7	0.1	0.3	0.2	-1.2
Wholesale and retail trade	50-55	2.5	0.2	0.4	-0.1	2.1	1.4	0.5	0.3	0.1	0.5	3.4	0.3	0.5	0.3	2.2
Sale, maintenance/repair motor vehicles; retail sale fuel	50	0.2	-0.1	0.3	0.0	0.0	1.0	0.6	0.3	0.2	-0.1	4.0	0.3	0.4	0.2	3.2
Wholesale trade/commission trade, except motor veh.	51	4.3	0.4	0.5	-0.1	3.5	1.9	0.6	0.4	0.0	1.0	3.6	0.4	0.8	0.6	1.9

Table A.5 (continued)

		Netherlands					**10 EU countries***					**US**				
	ISIC rev. 3	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**	**LP**	**Non-ICT**	**ICT**	**LC**	**TFP**
Retail trade, except motor veh.; repair household goods	52	0.6	0.2	0.3	0.0	0.2	1.2	0.4	0.2	0.1	0.4	3.0	0.2	0.3	0.4	2.0
Hotels and restaurants	55	-1.9	0.4	0.1	0.1	-2.5	-1.1	0.2	0.1	0.1	-1.6	0.7	0.2	0.2	0.4	-0.1
Transport, storage and communications	60-64	4.7	0.5	0.5	0.4	3.3	2.3	0.7	0.5	0.2	0.9	4.6	0.3	0.9	0.0	3.4
Transport and storage	60-63	1.7	0.3	0.4	0.4	0.5	0.8	0.8	0.3	0.2	-0.4	2.6	-0.1	0.7	0.4	1.6
Communications	64	11.6	1.5	1.1	0.5	8.5	5.6	0.8	1.0	0.3	3.5	7.2	1.0	1.4	0.2	4.9
Finance, insurance, real estate and business services	65-74	1.4	0.7	0.5	0.5	-0.3	0.1	0.0	0.4	0.1	-0.4	3.1	1.3	0.7	0.3	0.9
Financial intermediation	65-67	4.8	-0.9	1.2	0.9	3.7	2.4	-0.1	1.0	0.3	1.2	1.8	0.0	0.9	0.1	0.8
Real estate, renting and business activities	70-74	0.4	1.3	0.3	0.5	-1.7	-0.4	-0.2	0.3	0.2	-0.8	3.6	1.7	0.6	0.3	0.9
Real estate activities	70	-0.3	1.5	0.1	0.1	-2.0	-0.6	-0.5	0.1	0.0	-0.3	1.3	0.9	0.1	0.0	0.3
Renting of M&EQ and other business activities	71-74	0.2	0.5	0.4	0.7	-1.5	-0.1	0.2	0.6	0.3	-1.3	3.9	0.4	1.2	0.6	1.7
Community, social and personal services	75-99	0.0	0.1	0.3	0.5	-0.9	0.1	0.1	0.2	0.1	-0.4	0.9	0.3	0.2	0.2	0.1
Public administration/defence; compulsory social security	75	1.0	0.4	0.5	0.6	-0.4	1.3	0.3	0.3	0.3	0.4	1.3	0.5	0.3	0.2	0.3
Education	80	-1.3	-0.1	0.6	0.1	-1.9	-0.8	0.0	0.1	0.4	-1.4	0.2	0.2	0.3	0.4	-0.7
Health and social work	85	-0.7	-0.1	0.2	0.5	-1.2	0.8	0.2	0.2	0.2	0.3	1.1	0.3	0.2	0.3	0.1
Other community, social and personal services	90-93	1.1	0.1	0.4	0.9	-0.3	-0.7	0.2	0.2	0.1	-1.2	1.5	0.2	0.2	0.2	1.1
Grand total	01-99	1.6	0.3	0.3	0.5	0.4	1.1	0.5	0.3	0.2	0.1	2.5	0.6	0.5	0.2	1.2

* Weighted average of the following ten EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain and the UK.

Explanation: LP = labour productivity growth (growth of value added per hour worked); ICT = contribution of ICT capital deepening; Non-ICT = contribution of non-ICT capital deepening; LC = contribution of labour composition change; TFP = contribution of total factor productivity. Labour productivity growth in percentage changes and the contributions of the various components in percentage points were approximated by means of first differences of natural logarithms, which is in accordance with the growth accounting approach in the EU KLEMS database.

Source: calculations based on data from the EU KLEMS database (March 2008 update).

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CHAPTER 3

R&D and innovation: drivers of productivity growth

3.1 INTRODUCTION

In the huge body of empirical studies analysing productivity growth three drivers pop-up very frequently: innovation/R&D, ICT, human capital (for instance OECD, 2001; Khan and Luintel, 2006; Jorgenson *et al*., 2008). This chapter uses existing insights from the literature to analyse the contribution of R&D and innovation to productivity growth. The chapter also touches on the role of ICT, human capital and entrepreneurship for productivity growth.

This chapter is organised as follows. Section 3.2 provides an analytical framework to determine the drivers of labour productivity growth. Section 3.3 presents an overview of the empirical literature analysing the relationship between innovation and productivity growth. Section 3.4 gives insight into the potential impact of R&D and (technological) innovation on labour productivity growth. Policy options and implications accompanied with issues for future research conclude this chapter in Section 3.5.

3.2 ANALYTICAL FRAMEWORK

Labour productivity growth can be divided into two components: total factor productivity growth (or TFP growth) and the contribution of capital deepening. TFP growth is the 'residual' in a growth accounting framework, describing the productivity growth of the combined inputs capital and labour. Capital deepening reflects the increase of capital per unit of labour. Subsequently, this results in an increase in labour productivity. A Cobb-Douglas production function provides a simple framework to indicate the relationship between labour productivity growth on the one hand and TFP growth and capital deepening on the other hand. Equation (3.1) shows such a Cobb-Douglas production function, in which *Y* represents value added (volume), *K* symbolises capital (volume), *L* embodies labour and *TFP* is the indicator for total factor productivity.

$$Y = TFP\ K^{\alpha} L^{\beta} \tag{3.1}$$

Assuming constant returns to scale in the production factors capital and labour (i.e. $\alpha + \beta = 1.0$), it follows that:

$$Y/L = TFP \times (K/L)^{\alpha} \tag{3.2}$$

This leads to the following equation in percentage changes:

$$\dot{Y} - \dot{L} = \dot{TFP} + \alpha(\dot{K} - \dot{L}) \tag{3.3}$$

Equation (3.3) shows that the growth of TFP has a direct effect on labour productivity growth with an elasticity of 1.0. The contribution of capital deepening is equal to the growth of the capital/labour ratio, multiplied by the share of capital in the production function. A value of 1/3 is generally regarded as a realistic value of this share (Romer, 2001, p. 23). Capital deepening depends on quality improvements in capital goods and more generally the growth of investments in capital goods. Knowledge development can be regarded as a fundamental basis for growth in TFP. Structural TFP growth seems difficult to realise if it is not based on knowledge development. Innovation and the accumulation of human capital play a primary role in this.[25] Innovation also contributes to capital deepening through quality improvements in the stock of capital goods. This effect has occurred particularly in ICT capital. Since capital goods originate mostly from abroad, the effect of domestic innovations is limited here.

Domestic innovations do, however, have a significant *indirect* effect on the degree of capital deepening, through the relationship that exists in the longer term between TFP growth and the degree of capital deepening. This relationship follows from the neo-classical growth theory, which originates from Solow (1956) and can be elucidated as follows. As equation (3.3) shows, higher TFP growth leads by definition to higher labour productivity growth (the elasticity is 1.0). With a given deployment of labour, higher labour productivity growth translates into higher GDP growth. Assuming a given investment rate (investments as a percentage of GDP), higher GDP growth leads to a higher investment growth. The resulting accumulation of capital then leads to a stronger growth of the capital stock, and with it the capital/labour ratio. The

[25] We use a broad definition of TFP growth in our growth accounting framework in this chapter. This means that no separate effect of improvements in labour quality (human capital) is incorporated in the framework. Thus, TFP growth includes the contribution of quality improvements of labour. In Chapter 2 (Section 2.4), the improvement in labour quality is taken into account as a separate driver of productivity growth within the growth accounting framework.

higher growth of the capital/labour ratio gives a further boost to labour productivity growth (induced by the coefficient α in equation (3.3)). This produces a multiplier effect, where capital deepening and labour productivity growth increase until a new equilibrium is reached (a new steady state in accordance with the neo-classical growth theory). Assuming a weight of capital in the production function (represented by the coefficient α in equation (3.3)) of 1/3, a long-term multiplier of 1.5 can be calculated (=1/(1-1/3)). This implies that the TFP growth over the long term translates by a factor of 1.5 into labour productivity growth.

The line of reasoning in the preceding section, which leads to a multiplier of 1.5, is illustrated by equation (3.4) below. Two assumptions are needed to obtain this result: (i) the growth rate of the capital stock (*K*) equals the growth rate of gross investment (which is traditionally denoted as *I*) in the long run and (ii) given a constant investment rate the growth rate of gross investment equals the growth rate of value added (*Y*).[26] Given these assumptions, the growth rate of the capital stock may be substituted by the growth rate of value added in equation (3.3). Rearranging the terms in equation (3.3) results in the following long-run equilibrium relationship between labour productivity growth and TFP growth:

$$\dot{Y} - \dot{L} = \frac{1}{1-\alpha}\, T\dot{F}P \qquad (3.4)$$

3.3 INNOVATION AND PRODUCTIVITY: REVIEW OF THE LITERATURE

Technological change and innovation are regarded as major drivers of TFP growth. Technological innovation shifts the production frontier towards the origin, i.e., due to new technology the same level of production is reached with less input of both labour and capital. Technology diffusion reduces inefficiencies because it enables firms to reach, or come closer, to the production frontier. The incentive to reduce these inefficiencies will be stronger when the competitive pressure is higher. Competition weeds out firms with low productivity, and hence boost productivity. Moreover, higher skilled labour is better equipped to exploit the most novel technological insights, while the availability of the most recent ICT applications will enhance the exploitation of technological innovation.

It is obvious that the various drivers of productivity interact. A limitation of virtually all studies that try to explain labour productivity growth is that the interaction between the drivers is neglected; and moreover, most empirical studies are confined to one or two factors. It is extremely difficult, however, to disentangle the contribution of each of the determinants. See, for instance, Bartelsman and Doms (2000) for an extensive elucidation on the difficulties of assessing the relative importance of the factors driving productivity growth. A consequence of

[26] For the sake of simplicity we disregard quality changes of capital goods. Otherwise we would expect that the price increase of capital goods is less than that of value added.

the lack of interaction, and the limited number of drivers included in each study, is that the contribution of the separate determinants of productivity growth may be overestimated in the studies reviewed below.

3.3.1 Effects of innovation in the empirical literature

The effect of innovation on productivity has been analysed in various studies. Comparing these studies is difficult because of different levels of aggregation (country, industry or firm level), different interpretations given to innovation, and the various definitions of productivity: sometimes TFP, sometimes labour productivity and sometimes growth of value added (GDP growth). A limitation of most empirical research is that innovation is represented by R&D variables (growth of R&D capital or R&D intensity), whereas R&D is only one aspect of the total innovation process (see, e.g., Acs and Audretsch, 2005).[27] Ideally, the innovation system as a whole should be taken into account, but this is hampered by lack of data. It should be noted, however, that the greatest source of new knowledge is generally considered to be R&D (Cohen and Klepper, 1992). Hinloopen (2003), Faber and Hesen (2004) and Donselaar *et al*. (2007) confirm the importance of innovation expenditure (i.e. R&D expenditure) on innovation measured by the turnover due to new and significantly improved products.[28] From the study by Hinloopen (2003) a multiplier effect of 2.7 can be derived for the manufacturing sector. This multiplier effect means that one additional euro on innovation expenditure (i.e. R&D) in relation to total turnover in manufacturing leads 2.7 additional euros of turnover from new and improved products in manufacturing. In estimations conducted by Faber and Hesen (2004) this multiplier effect amounts to 3.7 euros. Besides the effect of innovation expenditure on innovation in *manufacturing*, Donselaar *et al*. (2007) also examine the *services sector*. The estimation results can be translated as follows: one additional euro on innovation expenditure (in relation to total turnover) in manufacturing results in a rise in turnover from new and improved products of 5.1 euros. In the services sectors, this multiplier effect is even higher: 5.8 euros. Based on these empirical results, we can reasonably assume that R&D is a sufficient indicator to represent the innovative capacity of countries. It is important, however, to keep in mind that a well-

[27] The definitions for *innovation* and *Research & Development* are taken from respectively the Oslo and Frascati Manual. The first *Oslo Manual* from 1992 used a narrow definition of innovation focusing only technological innovation in the business enterprise sector. The new Oslo Manual from 2005 uses a broader perspective of innovation, and also includes marketing and organisational innovation. Innovation in the new Oslo Manual is defined as (OECD, 2005): "*An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations. The minimum requirement for an innovation is that the product, process, marketing method or organizational method must be new (or significantly improved) to the firm.*" The Frascati Manual defines R&D as follows (OECD, 2002): "*Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.*"

[28] The turnover of new and significantly improved products is measured in the Community Innovation Survey (CIS), conducted by Eurostat: http://epp.eurostat.ec.europa.eu. Innovation expenditure is also measured in CIS and covers a somewhat broader definition than R&D expenditure (see Statistics Netherlands, 2006, pp. 187-201). Nevertheless, both input indicators of innovation are generally equivalent.

functioning (dynamic) innovation system is a necessary condition to reap the full potential benefits of R&D.

Despite the various approaches in the empirical literature investigating the relationship between R&D/innovation and productivity, the evidence clearly points at R&D/innovation as one of the main drivers of productivity growth at the three levels of aggregation: macro, meso and micro. We summarise the findings below.

The general features of the contribution of R&D to *macro*economic productivity are as follows:

- It pays to invest in R&D. In the long term, one additional euro spent on R&D leads to a multiple of this amount in terms of value added. This multiplier seems to be at least 5, but could possibly be higher than 10 (Coe and Helpman, 1995; Guellec and Van Pottelsberghe de la Potterie, 2004; OECD, 2000; Bassanini *et al.*, 2001). Business R&D contributes more to productivity growth than public R&D.
- Countries benefit from each other's R&D expenditure, through international R&D spillovers (Coe and Helpman, 1995; Guellec and Van Pottelsberghe de la Potterie, 2004). Small countries benefit the most from foreign R&D. Estimation results for the private sector by Coe and Helpman suggest that for 15 'smaller' OECD countries the elasticities of foreign R&D capital on TFP growth are five times larger than for G7 countries. Smaller countries, however, must invest in R&D too in order to assimilate new foreign knowledge (absorption capacity).
- Cohen and Levinthal (1989) emphasised that (intramural) R&D has two faces: (i) these R&D efforts are necessary for the creation of knowledge within the firm and (ii) intramural R&D is required for the exploitation of external knowledge. Thus, countries with a relatively low level of technological development can benefit from knowledge developed elsewhere by using it in their own products or production processes. Through catching-up, these countries can narrow the gap in productivity with the technological leader. A country's own R&D and human capital contribute positively to the speed of this catching-up process (Griffith *et al.*, 2004).
- The results in Verspagen (2001) suggest that the relative importance of (significant) innovations based on R&D within firms has been growing in recent decades. The narrowing of the productivity gap between a country and the technological leader in the world through catching-up is becoming more and more difficult due to the increasing complexity of the process of knowledge creation by means of R&D activities. Therefore, a country needs a higher R&D intensity of its own in order to absorb newly developed knowledge.

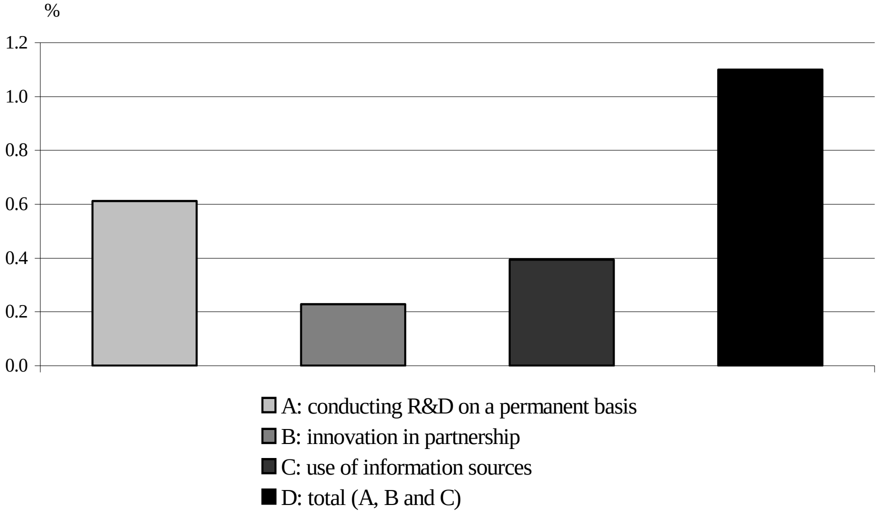
The positive effect of R&D on productivity is confirmed in research at the *industry* level. In this literature (domestic) R&D capital is usually divided into R&D capital in an industry itself, and R&D capital in other industries. In this way, account is taken of *spillover effects* between industries. Firms in an industry can benefit from R&D activities that are undertaken elsewhere. The extent of spillovers is difficult to establish because of measurement problems and incomplete data. Griliches (1979, 1992) discriminates between knowledge spillover effects and ‘rent spillovers’ (see also Scitovsky, 1954). Knowledge spillover effects captures the knowledge diffusion between firms, whereas rent spillovers encompass quality improvements of intermediate goods trade.[29] Two studies that mainly focus on knowledge spillover effects across industries are from Frantzen (2002) and Verspagen (1997). Frantzen (2002) shows that the influence of domestic R&D is stronger in large economies and that this is caused by more important domestic intersectoral R&D spillovers. Mohnen (1996) concludes in a literature survey that *knowledge spillover effects* account for 50-100% of the direct effects within firms or in industries where R&D is undertaken. In a literature survey by Nadiri (1993), the conclusion is drawn that the social return on R&D in the various studies averages about 50%, which is considerably higher than the private return of 20-30%. Mohnen (1996) argues that the social return on R&D is likely to be underestimated in many studies, because spillovers are often estimated only for a limited number of firms and industries. Spillovers to the *service sector* are very occasionally measured, while these sectors are major users of innovations developed in manufacturing. In their empirical research Jacobs, Nahuis and Tang (2002) find that spillovers are important for the productivity development in both manufacturing and non-manufacturing industries. This research also shows that in both manufacturing and non-manufacturing industries a business’ own R&D is important to absorb spillovers. While no significant direct effect of R&D in the non-manufacturing industries was found on the productivity development in these industries, R&D in the non-manufacturing industries appears to be particularly important for using knowledge developed elsewhere. Applying this knowledge often goes hand in hand with non-technological innovation. The combination of both types of innovation appears to promote business performance above all.

At the *micro* level too, it is found that R&D and innovation have a positive effect on business performance (Jaffe, 1986, 1988; Megna and Mueller, 1991). More recent studies that show a significant contribution of R&D in enhancing firm productivity are from Wakelin (2001), Klette and Kortum (2004) and Lööf and Heshmati (2006). The elasticities from micro-level research vary between 0.05 and 0.25. In a very recent study by Potters *et al.* (2008) it is found that the coefficient of R&D on firm productivity increases monotonically when moving from the low-tech to the medium-high and high-tech sectors, ranging from a minimum of 0.05/0.07 to a maximum of 0.16/0.18. Although micro-level research examining the link between R&D and productivity is increasing significantly due to increasing availability of micro-level data, a problem with micro-level research remains that spillover effects are not captured. Spillover effects from R&D are only included at a higher level of aggregation, i.e. the industry and macro level.

[29] Griliches (1992) argues: *“These type of rent externalities would not exist if the complete quality adjusted price of new and/or improved products could be determined accurately, for then productivity increases could be attributed to technological progress in the correct industry, i.e. to the industry where it actually originated.”*

An interesting addition of the analyses conducted at the micro level (compared to the industry and macro level) is that for individual firms, recent studies have also examined the effect of innovation, rather than the effects of merely R&D on productivity. For example, it appears that firms that are the most active in the innovation process – by means of, for instance, co-operation and the support of knowledge contacts – achieve the highest improvement in business performance (see Figure 3.1 for an illustration).

Figure 3.1 Effects of innovative activities on the (annual) turnover growth, manufacturing and other non-service industries, period 1996-1998



Source: Statistics Netherlands (2001, page 163).

3.3.2 Related determinants: ICT, human capital and entrepreneurship

ICT, human capital and entrepreneurship are determinants of productivity growth that are closely related to innovation.[30] These determinants are discussed here briefly. The importance of these factors, amongst other factors, for productivity growth is more comprehensively dealt with in Chapter 9.

It is undisputed that *ICT* improves productivity. There is a direct effect in the sense that labour productivity in the ICT sector grows fast as a result of innovation. Jorgenson *et al.* (2008) show

[30] Other factors, such as competition and spatial planning also play a stimulating role in productivity development, but are not extensively dealt with in this dissertation. Competition, for instance, keeps firms alert and encourages them to raise productivity. The effect of market forces on innovation in particular are important here. In general, the literature shows that product market competition fosters innovation and productivity, especially if the level of competition is not too intense (cf. Nickell, 1996; Blundell *et* al., 1999; Aghion *et al.*, 2005; CPB, 2002a, page 218).

that information technology emerges as the driving force behind the acceleration of US' labour productivity growth that began in the mid-1990s. Furthermore, there is a direct contribution through capital deepening: labour productivity rises as a result of a higher utilisation of ICT capital per worker.[31] ICT also affects TFP positively as a result of the utilisation of ICT applications in combination with organisational changes. Finally, the use of ICT in firms may increase productivity in other firms through so-called ICT spillovers, although in Chapter 2 of this dissertation it is argued that this link is not unambiguous.

Investing in *human capital* also increases labour productivity (cf. Engelbrecht, 1997; Bassanini and Scarpetta, 2002).[32] The accumulation of human capital provides a direct contribution to labour productivity growth. Human capital also ensures a more effective use of foreign knowledge, thus a faster catching-up process towards the productivity level of the technological leader (see, for instance, Dowrick and Rogers, 2002). The effect of human capital on innovative ability is not yet that clear in empirical terms, although a limited number of studies suggest that human capital affects the innovative ability of firms positively (see, for instance, Frantzen, 2000). In any case, human capital is a very important input factor for the innovation process. Therefore, the external effects of R&D (through spillovers) must also be interpreted in terms of (dynamic) externalities of human capital (see for empirical evidence Moretti, 2004).

The direct contribution of *entrepreneurship* to productivity on a macro or regional level has been subject of empirical study to a very limited extent. Audretsch and Keilbach (2004a, 2004b and 2004c) conducted three studies where they considered the relationship between start-up rates in German regions and labour productivity growth. In each study they find a significant positive effect of entrepreneurship. However, all three studies remain limited to data covering German regions and few years of observation. Holtz-Eakin and Kao (2003) find a significant positive relationship between birth and death rates and productivity levels in cross-section panel estimations for US states. However, estimations using the 'within' variation of productivity across US states sketch a different picture: the effects of the lagged values of the birth and death rate on productivity are insignificant and show negative signs.[33] In short, on a macro level of analysis there appears to be no study that finds a clear long-term relationship between entrepreneurship and productivity. Chapter 9 of this thesis tries to fill this empirical gap in the literature and looks at this long-run relationship more explicitly. At the firm level there is a much larger body of literature that confirms a positive relationship between entrepreneurship

[31] Based on the growth accounting framework (see Donselaar *et al.* (2003b) for more details) the annual contribution of ICT capital to labour productivity growth in the 1990s is approximately 0.5 percentage points on average in the OECD countries (Van der Wiel, 2001). The Netherlands matches the OECD with regard to the contribution of ICT capital (see also Chapter 2 of this dissertation).

[32] According to empirical research by Bassanini and Scarpetta (2001, 2002), an increase by one year in the average duration of education among the population aged 25-64 years leads to a 6% increase in GDP per capita in the long term.

[33] These 'within' estimates – preferred by the authors – imply that each variable is transformed to deviations from the state-specific mean. This way, state-specific effects are filtered out, which obviates possible unobserved heterogeneity.

and productivity growth (for instance Disney *et al.*, 2003; Foster *et al*., 2006).[34] In addition, entrepreneurship does also deliver an indirect contribution to productivity growth through innovation. It is not innovation in general that is fostered by entrepreneurship (see Van Praag and Versloot (2007) for an overview), but entrepreneurship does seem to stimulate radical innovations and the commercialisation of innovation (see, for instance, Love and Ashcroft, 1999; Czarnitzki and Kraft, 2004; Lowe and Ziedonis, 2007 and Dechenaux *et al*., 2003). This relates to the idea of entrepreneurship as an important mechanism to transfer knowledge into economically relevant knowledge which could lead to innovations, which was addressed in Chapter 1 of this dissertation.

3.4 CONTRIBUTION OF INNOVATION TO PRODUCTIVITY GROWTH

This section gives a quantification of the contribution of innovation to productivity growth. The emphasis is on the explanation of TFP growth by the broad concept of innovation, which is represented by R&D as the main input in the innovation process. R&D also captures the effects of human capital and ICT, insofar as they enhance the innovation process directly.[35] Based on the findings in a couple of empirical studies on the relationship between innovation and productivity at the macro level and based on a few additional assumptions we compute the structural contribution of innovation to productivity growth in Section 3.4.1. Subsequently, we confront this structural contribution with the actual one in the Netherlands in the 1990s (Section 3.4.2). Section 3.4.3 shows that the level of R&D intensity does not affect structural TFP growth. Section 3.4.4, however, demonstrates that the level of TFP does benefit from an increase of the R&D intensity.

3.4.1 Structural contribution of innovation to productivity growth

In general, the contribution of innovation to productivity growth is examined empirically by quantifying the effect of R&D capital on productivity development. We base our quantification on two studies at the *macro* level which we believe represent a large body of empirical studies: Guellec and Van Pottelsberghe de la Potterie (2004) and Coe and Helpman (1995). According to the OECD study by Guellec and Van Pottelsberghe de la Potterie, 1% additional R&D capital in firms leads to an increase in the TFP level of firms by 0.13%. According to a study by Coe and Helpman (1995), for small countries (such as the Netherlands) this elasticity is 0.08 and for the G7 countries 0.23. These values can be considered as long-term elasticities with regard to the effect of R&D expenditure on TFP. R&D expenditure in fact affects the stock of R&D capital through an accumulation function. In the long term, an increase of R&D expenditure by 1% leads to an additional 1% of R&D capital. R&D expenditure, however, needs to be deflated

[34] Concerning productivity *levels*, firm-level research shows that entrepreneurs do not seem to have higher, and probably lower, productivity levels than incumbent firms (see Van Praag and Versloot, 2007, p. 368 and 369).

[35] Chapter 4 in Donselaar *et al.* (2003b) describes in more detail both the direct and indirect effects of human capital and ICT on productivity growth.

first, in order to take account of inflation and/or cost increases. In the study by Guellec and Van Pottelsberghe de la Potterie, R&D expenditure is deflated by a GDP deflator, and in the study by Coe and Helpman by a constructed price index for R&D. 50% of this index is determined by the price level of the value added of businesses and 50% by the average wage rate in the business sector. In this way, Coe and Helpman take account of the fact that about half of all R&D expenditure consists of wage costs. This has consequences for the development of the stock of R&D capital, since wage costs rise faster on average than the price level of value added. Assuming a realistic increase in (real) wage costs of 1% on average annually, the development of the stock of R&D capital, according to the approach of Coe and Helpman, would increase each year by an average of 0.5 percentage points less than according to the approach of Guellec and Van Pottelsberghe de la Potterie.

What does the above mean for the structural, annual *contribution to TFP growth* that may be expected from *R&D expenditure by enterprises*? We conduct calculations based on the simplified assumption that the R&D intensity remains constant over time. This implies that R&D expenditure increases at the same rate as GDP and, subsequently, economic growth determines the growth rate of the R&D capital stock. If R&D expenditure is deflated using the GDP price level, then R&D expenditure grows as fast as GDP and, in the long term, the growth rate of the R&D capital stock equals economic growth. If one takes wage cost increases into account in determining *real* R&D expenditure, then – assuming a *real* wage cost increase of 1% per year – the growth rate of the R&D capital stock lags behind economic growth by 0.5 percentage points in the long term. Under the assumption of an annual economic growth rate of 2.5 to 3%, a structural annual growth rate of the R&D capital stock between 2% to 2.5% can be expected. Using the elasticity of Coe and Helpman of 0.08 for a small economy, this leads to a structural contribution to TFP growth in the Netherlands of 0.2 annually.

Public R&D is important for productivity development too. According to the study by Guellec and Van Pottelsberghe de la Potterie, the effect of public R&D on TFP is roughly as high as that of private R&D. This is a remarkable result in the sense that a considerable part of public R&D takes place in scientific fields that are not directly relevant for technological development in enterprises (think, for example, of linguistics). According to another OECD study (Bassanini *et al.*, 2001), on the other hand, the effect of public R&D is negative; a result which is difficult to explain. As Van Sinderen (2001) points out concerning these two conflicting results, the truth will probably lie somewhere in between. In the MESEMET model of the Ministry of Economic Affairs (see Donselaar *et al.*, 2000) it is assumed that the effect of public R&D on productivity is roughly half as high as that of private R&D. Here we will adopt this assumption, which, given an economic growth trend of 2.5% to 3%, leads to a structural contribution of public R&D to annual TFP growth of 0.1 percentage points.

According to empirical studies, *R&D expenditure abroad* is also important for the development of TFP. This concerns spillover effects from foreign R&D capital. Coe and Helpman estimate an elasticity of 0.16 for the effect of foreign R&D capital on TFP growth in the Netherlands. Guellec and Van Pottelsberghe de la Potterie find an elasticity which amounts to as much as 0.45. By way of precaution we will use here the coefficient of Coe and Helpman (of 0.16). Assuming an economic growth rate in foreign countries of 2.5% to 3% and assuming a fixed level of foreign R&D intensity, foreign R&D spillovers provide a structural contribution to annual TFP growth in the Netherlands of 0.3 to 0.4 percentage points. Once again, account is taken here of a real wage cost increase of 1% each year, which has a downward effect on the annual growth trend of foreign R&D capital of 0.5 percentage points. As already stated earlier in this chapter, it is important for firms in the Netherlands to conduct R&D themselves, otherwise they will not be able to absorb foreign R&D effectively. Thus, the above-mentioned significant contribution of foreign R&D to TFP growth in the Netherlands is partly dependent on the Dutch R&D capacity.

To summarise: on the given assumptions, private R&D have a structural annual contribution to TFP growth of 0.2 percentage point, public R&D of 0.1 percentage point and foreign R&D spillovers of 0.3 to 0.4 percentage point. The ultimate effect on labour productivity growth could be 1.5 times higher (via the multiplier mechanism as already addressed in Section 3.2).

3.4.2 Actual contribution of innovation to TFP growth in the Netherlands in the 1990s

The above-calculated contributions can be interpreted as *structural contributions* to the TFP-growth in the long run. These figures can also be used to calculate the *actual* contribution of R&D factors to productivity growth of a country during a certain period of time.[36] To conduct such a calculation one has to consider three elements: (i) the real wage costs; (ii) the economic growth and (iii) the R&D intensity. In case of the Netherlands during the period 1990-2000, the actual development of real wage costs was relatively modest (lower than the 1% structural increase that was assumed in the previous section) and economic growth was relatively high (almost 3% on average). On the other hand, the corporate R&D intensity in the Netherlands in the 1990s was about 0.2 percentage points lower than in the second half of the 1980s (Statistics Netherlands, 2000, p. 207). This had a downward effect on the growth of the stock of R&D in the Netherlands during the 1990s. For countries abroad the annual economic growth was 2.3% in the 1990s (CPB, 2002b, appendices to Macro Economic Outlook). This is a little less than the 2.5% to 3% which was assumed in calculating the structural contribution of foreign R&D. The development of real wage costs abroad was in line with the 1% that was hypothesized in the calculation. Finally, the private R&D intensity in the OECD in the 1990s was slightly lower than in the second half of the 1980s. The resulting downward effect on the growth of the foreign

[36] The analysis in this section is a *stylised version* of the actual situation. First, the R&D variables also capture the indirect impact of ICT and human capital on innovation and therefore on productivity growth. Donselaar *et al.* (2003a) decompose productivity growth into various factors. Next to R&D effects, they include human capital and capital deepening effects (ICT and other capital) as separate components. However, even in this analysis some other factors are neglected. This is for instance the case for entrepreneurship, competition and regulation, and spatial planning.

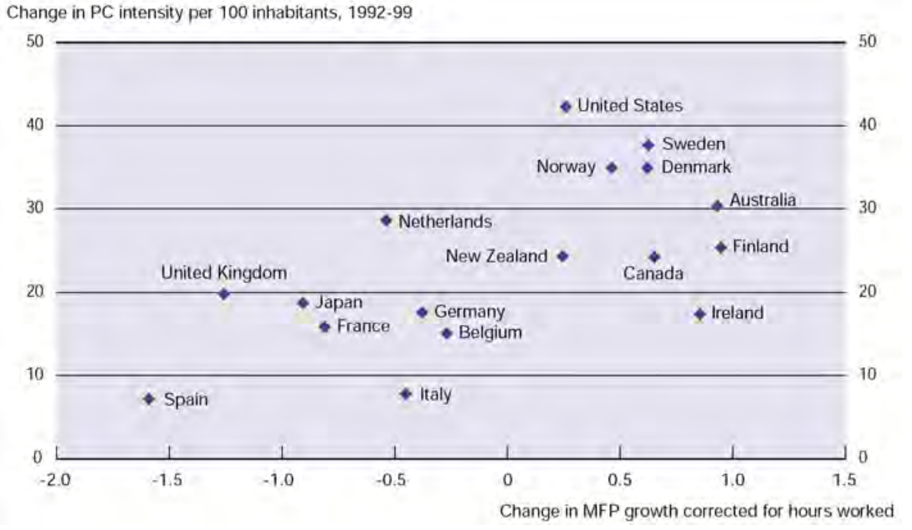
R&D capital stock is counterbalanced by the fact that average R&D intensity in the 1990s was higher than in the first half of the 1980s (Statistics Netherlands, 2000, page 207).

Taking all the above into account, private R&D capital in the Netherlands has made an average annual contribution to TFP growth in the period 1990-2000 of 0.2 percentage point, public R&D expenditure an average annual contribution of 0.1 percentage point and foreign R&D spillovers an average annual contribution of 0.3 percentage point. Thus, for domestic R&D – private and public – we have maintained the calculated percentages for the structural contribution. For foreign R&D spillovers the lower limit of the margin for the structural contribution (0.3 to 0.4 percentage point) is chosen.

3.4.3 Role of the level of R&D intensity

The business R&D intensity in the Netherlands (1.02% in 2005) is lower than the EU average (1.21% in 2005) and substantially below the OECD average (1.59% in 2004).[37] This low level of R&D intensity in the private sector is often judged as an impediment to structural TFP growth.

Figure 3.2 Change in business R&D intensity and change in TFP growth; average in the 1990s compared with the average in the 1980s



Source: OECD (2001, page 43).

[37] The public R&D intensity (0.72% in 2005) in the Netherlands, on the other hand, is above the EU (0.66% in 2005) and OECD average (0.66% in 2004) (see OECD, 2006).

However, according to the prevailing approach in the literature, the *level of R&D intensity does not have a (decisive) effect on the long-term growth rate of TFP*. This is also a feature of the R&D capital approach, which is used in the studies from Coe and Helpman (1995) and Guellec and Van Pottelsberghe de la Potterie (2004). According to the R&D capital approach, an increase in R&D intensity would only have a temporary effect on the growth of R&D capital. This implies that only a temporary effect on TFP growth can be achieved. Although TFP growth in the long term can be considered as (largely) independent of the level of R&D intensity, an increase in R&D intensity can indeed give a *temporary* impetus to TFP growth (see Figure 3.2).

3.4.4 Potential contribution of a structural increase in the private R&D intensity on the level of TFP and labour productivity

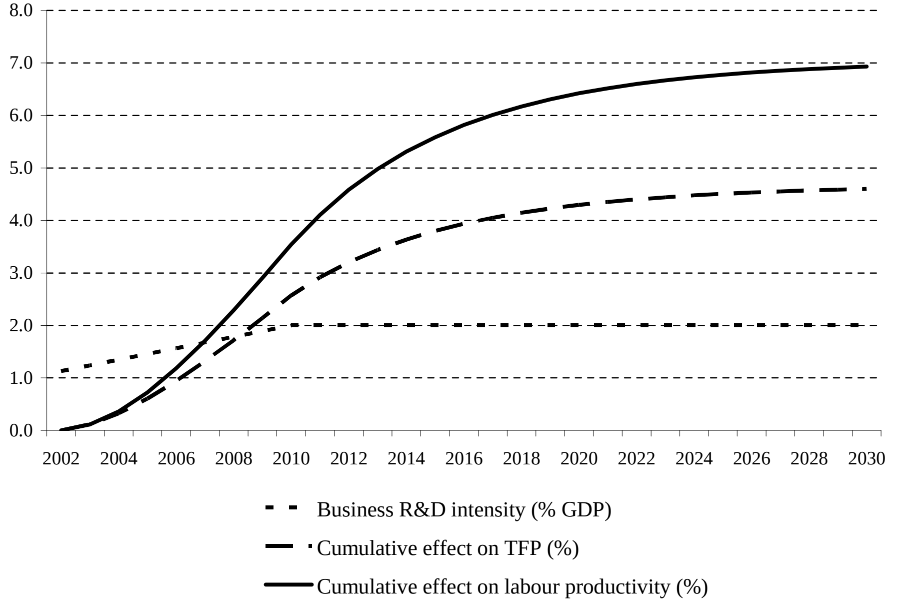
The analysis in the previous section suggests that an increase in the R&D intensity boosts the level of labour productivity. The empirical results in Coe and Helpman (1995) serves as a guide for the magnitude of this effect. Below we elucidate these effects for an increase in the levels of domestic private R&D intensity and foreign R&D intensity.

Based on the study of Coe and Helpman (1995) we can calculate that a (structural) increase in business R&D intensity in the Netherlands by 10% leads to an increase in TFP by 0.8% (= 0.08 × 10%) in the long run. Adopting the situation in 2001 as our point of departure, a 10% increase in R&D intensity leads to an absolute increase in the R&D intensity of 0.11 percentage points (= 0.10 × 1.08%). Taking into account the extra capital deepening effect as a result of an increase in TFP, labour productivity in the business sector increases by ultimately 1.2% (= 1.5 × 0.8%). This is approximately 8.5 times as much as the additional R&D expenditure as a percentage of value added in the business sector (0.11% of GDP, which is equal to 0.14% of the gross value added in the business sector, assuming a share of the business sector in total GDP of 80%). In other words: one additional euro on business R&D has a productivity effect in the long term that is equivalent to 8.5 euro additional value added (assuming a given deployment of labour).

According to the empirical results of Coe and Helpman, an increase in foreign R&D intensity is even more beneficial to productivity development in small open economies, such as the Netherlands. A 10% increase in R&D intensity abroad would increase the TFP level in the Netherlands by 1.6% (= 0.16 × 10%) in the long term, from which a 2.4% (= 1.5 × 1.6%) increase in labour productivity follows. The level of the business R&D intensity in the OECD in 2001 was 1.62%. Thus, a 10% increase of the private R&D intensity abroad amounts to 0.16% of GDP, which is 0.20% of the value added of the business sector abroad (assuming a share of 80% of the business sector in total GDP abroad). Labour productivity in the Netherlands thus increases about twelvefold compared to the absolute increase in the average R&D intensity abroad as a percentage of the value added of businesses abroad.

The calculations above illustrate that labour productivity of a country depends on both its own R&D intensity as well as R&D conducted abroad. This supports the 3% target agreed upon during the European Summit in Barcelona in March 2002. In this 'Barcelona objective' the aim is to raise the average R&D expenditure in the EU to 3% of GDP in 2010, of which two-thirds is financed by firms (European Council, 2002; European Commission, 2002). For both the Netherlands and the EU as a whole, this would entail approximately a doubling of the business R&D intensity, while in the EU as a whole, public R&D activity needs to be increased substantially as well.

Figure 3.3 Effects of realising the Barcelona objective for business R&D expenditure in the Netherlands (period 2002-2030)



Calculations based on the coefficients from the study of Coe and Helpman (1995) indicate that realising the Barcelona ambition for private R&D expenditure would lead to an additional 15% labour productivity in the Netherlands in the long run. Of this long-term effect 7 percentage points are related to an increase in private R&D activity in the Netherlands, while the other 8 percentage points are the result of higher private R&D activity in the other EU countries.[38]

[38] Account has been taken in these calculations of diminishing returns from R&D, since these play a major role in case of a sharp increase in R&D intensity. The preceding calculations, which involve a smaller increase in R&D intensity of 10% at home and abroad, ignore this aspect. Account can be taken of the diminishing returns from R&D by taking the log-linear specification as estimated by Coe and Helpman (1995) for TFP development as the starting point for the calculations. Coefficients smaller than 1 for the R&D variables imply that – within a log-linear specification – there are diminishing returns from R&D.

Figure 3.3 demonstrates the possible effects on TFP and labour productivity resulting from an increase of the business R&D intensity in the Netherlands from the current 1.0% to 2.0% in 2010, in line with the Barcelona objective.

A necessary condition for substantial effects to occur is that additional R&D expenditure goes hand in hand with additional availability of R&D personnel. This prevents sharp wage increases of R&D workers. Policy aimed at increasing the availability of R&D personnel could fulfil this condition. Such policy seems to be important in the Netherlands in the years to come. In the Dutch construction sector, for example, major shortages of science and engineering personnel are expected (De Graaf *et al*., 2007; De Grip and Smits, 2007). The same counts for university-level mechanics and electrical engineers (ibidem). In these sectors, there is a great demand both for additional and replacement personnel, while the number of graduates in the relevant subjects is expected to be average to low over the coming years. In addition, shortages in these sectors can hardly be offset by the employment of foreign personnel. It is expected that annual shortages in these sector will continue until at least 2020. If the R&D intensity is to increase in the near future, this evidently puts even more pressure at the availability of researchers of Dutch origin (especially in these industries).

3.5 CONCLUSIONS, POLICY IMPLICATIONS AND FUTURE RESEARCH

It is undisputed that R&D and innovation are main determinants of productivity growth. The (theoretical) production function approach points to the importance of ICT with respect to the capital deepening effect, while R&D/innovation, human capital, and entrepreneurship are important factors for the increase in the total factor productivity (TFP).[39] Empirical research at various levels of aggregation confirms the strong impact of R&D and innovation on productivity growth. Business R&D contributes the most to productivity growth. Furthermore, a small and open economy like the Netherlands benefits heavily from foreign R&D expenditure through international spillovers. Smaller countries, however, must invest in R&D too in order to assimilate new foreign knowledge (absorption capacity). Moreover, small countries like the Netherlands require a threshold in the R&D intensity which seems to increase. The increasing complexity of the process of knowledge creation through R&D activities implies that a country needs a higher R&D intensity of its own in order to absorb newly developed knowledge.

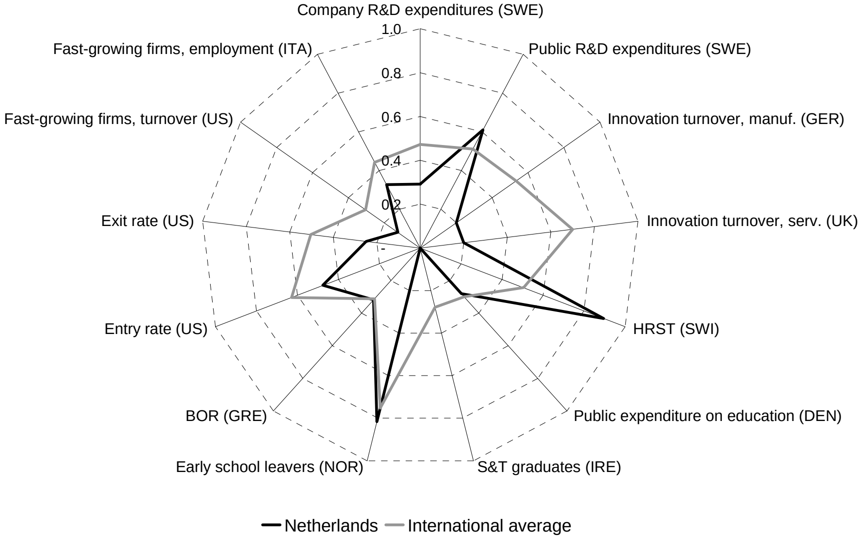
Benchmarking three drivers of total factor productivity

For policymakers it is important to determine the relative position on the three determinants of total factor productivity brought into focus in this chapter, i.e. R&D/innovation, human capital

[39] In Chapter 2 (Table 2.2, Table A.4 and Table A.5) human capital deepening was separated from the TFP component as an independent driver of productivity growth, denoted by the contribution of changes in labour composition. In this chapter – as well as Chapter 9 – a broad definition of TFP growth is used, meaning that the contribution of human capital capital deepening to productivity growth is incorporated in TFP growth.

and entrepreneurship. If the Netherlands already has a good position vis-à-vis other countries, the scope to improve on a certain driver of productivity is probably limited and vice versa. In Figure 3.4 the position of the Netherlands on some elements of R&D/innovation, human capital and entrepreneurship as the drivers of TFP is benchmarked internationally.

Figure 3.4 Dutch performance on innovation/R&D, human capital and entrepreneurship vis-à-vis a weighted international average



Commentary: see the annex for more information on the sources, years and countries.

The country that has the higher international performance on a certain indicator is shown between brackets. The indicators are standardised using the following formula:

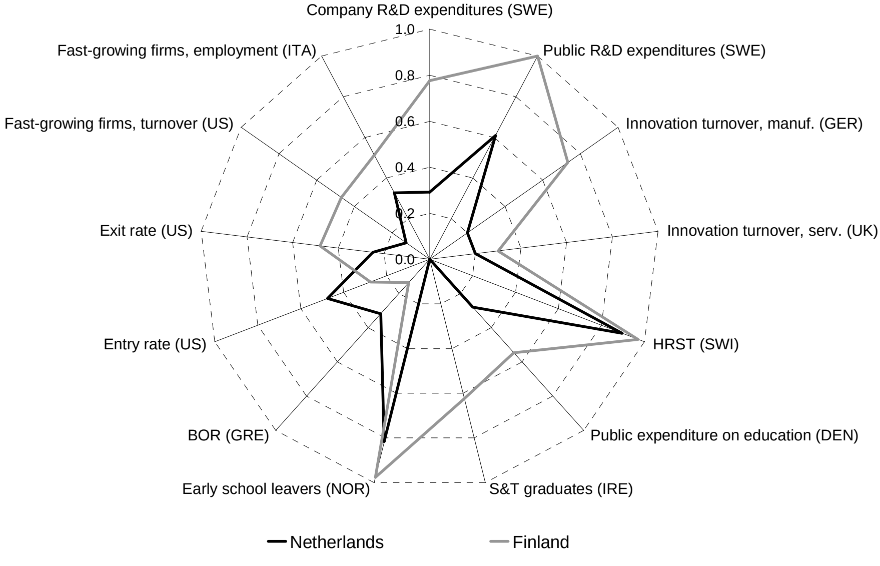
$$y = \frac{x_{i,t} - \min_{i,t}(x_{i,t})}{\max_{i,t}(x_{i,t}) - \min_{i,t}(x_{i,t})} \tag{3.5}$$

In equation (3.5), x represents the value on an indicator for country i (in our case the Netherlands) for a certain time range t. 'Min' and 'max' are the minimum and maximum values within a group of reference countries. These reference countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US. The consequence of this method is that for each indicator the best performing country gets a score of

1 and the worst performing country gets a score of 0.[40] The other countries get a score between 0 and 1. An overview of the definition of each indicator, sources used and the years of observation can be found in the annex (see Table A.1).

Beginning at the top of Figure 3.4 in a clockwise rotation, first innovation-related drivers are presented, followed by human capital variables and entrepreneurship indicators at two-thirds of the figure. Although other indicators for innovation/R&D, human capital and entrepreneurship are conceivable, Figure 3.4 provides an acceptable view of the position of the Netherlands on these drivers of total factor productivity. The Netherlands only performs above the international average on public R&D intensity, human resources in science and technology and early school leavers. On the other indicators the Netherlands performs beneath the international average. Most prominent is the Dutch score on corporate R&D expenditure, innovation turnover and the percentage of science and technology graduates.

Figure 3.5 Dutch performance on innovation/R&D, human capital and entrepreneurship vis-à-vis a weighted international average, the Netherlands vis-à-vis Finland



Commentary: see the annex for more information on the sources, years and countries.

40 For the indicator early school leavers an inverse scale is used: $y = 1 - \left[\frac{x_{i,t} - \min_{i,t}(x_{i,t})}{\max_{i,t}(x_{i,t}) - \min_{i,t}(x_{i,t})} \right]$. This implies that country with the highest rate of early school leavers gets a score of 0 in Figure 3.4 and 3.5, whereas the country with the lowest amount of early school leavers gets a score of 1.0.

More interestingly, in Figure 3.5 the Dutch position is benchmarked with Finland, a country that shows high productivity growth as a result of TFP growth (see Table 2.2 of Chapter 2). Although Finland has a lower score on some entrepreneurship indicators, it has a much better position on indicators related to innovation/R&D, S&T graduates and fast-growing firms. To a large degree, these three drivers of total factor productivity are interrelated: scientists and engineers are an important input factor for R&D processes; R&D is the main source of new knowledge and innovation; and innovation constitutes an important source of firm competitiveness which, as a result, enables the fast growth of businesses. This observation is in accordance with the claim in this chapter that the innovation capacity of countries is an important determinant of total factor productivity growth.

How may the government stimulate R&D activities among firms?
The previous benchmark analyses yield the important question as how to stimulate R&D/innovation in the Netherlands and ultimately productivity growth. A strong justification for public support of private R&D follows from empirical evidence indicating that social returns from R&D substantially exceed private returns (e.g. Scherer, 1982; Jones and Willams, 1998; Hall, 1996). The limited private returns makes that firms underinvest in R&D and innovation. Adopting a conservative private rate of return to R&D investments of 30%, Jones and Williams (1998) illustrate that the optimal level of R&D investment in the US is at least four times larger than actual R&D investment. Public support may bring investment in R&D at a socially optimal level. In recent years, R&D and innovation were amongst the most important topics on the EU policy agenda. The EU leaders concluded that investment in the knowledge-based economy (Lisbon Summit in 2002) and in R&D expenditures (Barcelona Summit in 2002) are key. In Chapters 5 and 6 we pay specific attention how the R&D intensity in countries can be raised. For now, we focus on two specific well-known policy instruments in the Netherland, which are a R&D tax incentive called the WBSO and a scheme to enhance the co-operation between the public knowledge infrastructure and the private sector.

The Dutch tax credit scheme to support R&D within firms is called the WBSO. Two evaluation studies of the WBSO scheme based on micro-level data show quite promising results with regard to its effectiveness (additionality and accessibility) and its low administrative burden. The first evaluation of the WBSO was conducted by Brouwer *et al.* (2002). They find a multiplier effect of the WBSO on the R&D wage sum of 1.02.[41] In the second WBSO evaluation, a joint effort by De Jong and Verhoeven (2007) and Lokshin and Mohnen (2007), an even higher multiplier of the WBSO on the R&D wage sum was found of 1.27. Other international studies confirm a multiplier effect of R&D tax incentives on private R&D expenditure of approximately 1.0 (Hall and Van Reenen, 2000; Bloom *et al.*, 2002).[42]

[41] This multiplier mechanism means that one additional euro of fiscal R&D stimulation leads to one additional euro spend on R&D by firms.

[42] Guellec and Van Pottelsberghe (2003), however, find a multiplier which is considerably lower than 1.0. The results from their panel data analysis for 17 OECD countries for the period 1984-1996 can be converted into a multiplier of approximately 0.3.

ICT and other general-purpose technologies (like biotechnology) play a prominent role in the efforts to foster the co-operation between the various actors in the innovation system, like private firms, universities and research institutes. Although empirical evidence is limited – Berman (1990) is one of the few empirical studies that examines the impact of public-private interaction on private R&D expenditure – R&D collaboration is expected to benefit private R&D expenditure (see Porter and Ketels, 2003). The role of the government is most obvious in fields of technology where research results can not be easily translated into new products that may be launched on the market (for instance nanotechnology). The Dutch Leading Technological Institutes received the designation of 'good practice' from the OECD (2003).[43] These institutes are mainly virtual and constitute an innovative model for public-private collaboration in a number of selected fields: telematics, food, polymers and metals. Each of these four institutes brings together a number of public research organisations (e.g. universities, national research centers) and industrial partners. The resulting network combines the strengths of the best researchers in the Netherlands, engages them in industrially relevant programmes, and helps co-ordinate research activities in areas of strategic relevance to Dutch society.

Future research: a model integrating the impact of drivers of productivity growth?
A limitation of most empirical studies on productivity growth is that one or at most a few factors driving productivity growth are discussed. Each determinant of productivity is dependent on a wide array of factors itself which are often not exogenous and interrelated to a high degree as well (see, for instance, Bartelsman and De Groot, 2004). The analysis in Chapter 9 more integrally approaches various drivers of productivity growth and could function as a starting point for a hierarchical framework which also incorporates policy factors. Such a framework would be of great help for policymakers finding a balance between various policy options. Ideally, the analysis would give an answer to policymakers in which situation R&D subsidies, and in which situation measures to improve the skills of knowledge workers, would be most effective for strengthening the innovative capacity of a country and boosting productivity growth. Although the OECD (2008) is busy working on a simulation framework which models the impact of several (policy) drivers of GDP per capita, there is still a lot of work to be done. The partial approach chosen by the OECD, for instance, ignores various complex interrelations between determinants of growth.

Although it seems unrealistic to expect that a holistic framework will be available in the short run, we make a plea for research efforts which try to increase our insights into the interdependencies of the various determinants of growth. The linkage of large micro-level data sets enables us to incorporate a large number of drivers of growth into one model. The availability of micro-level data sets also provides the opportunity to better compare the effects at the different levels of aggregation. A first impression based on our analysis is, for instance, that the productivity effects of R&D at the macro level are substantially higher than the effects at the

[43] In several interviews with the Ministry of Economic Affairs, R&D managers of various leading Dutch R&D firms emphasized the importance of the Leading Technological Institutes for the Dutch innovation system.

micro level. Are the spillovers perhaps even higher than has been assumed up till now? Finally, we mention *policy experiments* as a source for improving innovation policies and expanding our scientific insight into the determinants of growth and innovative capacity. Small-scale experiments are an option to determine the effectiveness of a measure (CPB, 2002a).

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ANNEX

Table A.1 Data sources and years of observation of each variable used in spider diagrams (Section 3.5)

Variables	Definition	Reference Group	Source	Years of observation
Private R&D intensity	Private R&D expenditure as a percentage of gross domestic product	OECD	OECD MSTI	2000-2005
Public R&D intensity	Public R&D expenditure as a percentage of gross domestic product	OECD	OECD MSTI	2000-2005
Innovation turnover, manuf.	Turnover of new and improved products in manufacturing	EU25	CIS	2004
Innovation turnover, serv	Turnover of new and improved products in services sector	EU25	CIS	2004
Human resources in science and technology (as a percentage of total population, 25-64)	The definition of HRST (Human Resources in Science and Technology) is based on two criteria: educational level and profession. HRST is defined as all highly educated people with post-secondary education (ISCED Level 5 and above) and/or working in an S&T profession (Canberra Manual, 1995).	EU27	Eurostat	2000-2006
Public expenditure on education as a percentage of GDP	The public sector funds the education either by bearing directly the current and capital expenses of educational institutions (direct expenditure for educational institutions) or by supporting students and their families with scholarships and public loans as well as by transferring public subsidies for educational activities to private firms or non-profit organisations (transfers to private households and firms). Both types of transaction together are reported as total public expenditure on education.	EU27	Eurostat	2000-2005
Tertiary graduates in science and technology per 1 000 of population aged 20-29 years.	Science and engineering graduates are defined as all post-secondary graduates (ISCED 5a and above) in science, mathematics and computing, engineering, manufacturing and construction.	EU27	Eurostat	2000-2005
Early school leavers	Percentage of the population aged 18-24 with at most lower secondary education and not engaged in further education or training	EU27	Eurostat	2000-2006
Business ownership rate	Number of businesses older than 42 months as a percentage of the total labour force	Weighted average of 20 OECD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, the UK, the US and Switserland	Compendia	2000-2006

Table A.1 (continued)

Variables	Definition	Reference Group	Source	Years of observation
Entry rate	The number of new entrepreneurs who start a new ‘activity’ (company) or existing companies/entrepreneurs who start a new ‘activity’, divided by total labour force	Weighted average of 11 OECD countries: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, the UK and the US	EIM, OECD Economic Outlook	2000-2005
Exit rate	The number of firms that finished their activities, divided by the total number of companies in a certain country	Weighted average of 11 OECD countries: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, the UK and the US	EIM	2000-2005
Fast-growing firms, turnover	Enterprises with high sales growth of at least 60% over three years as a percentage of all firms with 50-1000 employees	Weighted average of 11 OECD countries: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, the UK and the US	EIM	2001-2004
Fast-growing firms, employment	Enterprises with high employment growth of at least 60% over three years as a percentage of all firms with 50-1000 employees	Weighted average of 11 OECD countries: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, the UK and the US	EIM	2001-2004

In: *Technovation*, 25(10), October 2005, pp. 1079 - 1092.

CHAPTER 4

Trends in R&D – A Dutch perspective

4.1 INTRODUCTION

For some time now there have been different and conflicting signals concerning research and development (R&D) in the Netherlands. On the one hand, there seems to be a negative development in the field of R&D, referring to events in the past regarding Fokker, DAF and Baan as well as the closure of the Ericsson site in Enschede and the Lucent site in Hilversum. In line with these observations, there are signals that indicate an increasing relocation of R&D to foreign locations, such as Unilever to India and DSM to Canada. Furthermore, research reports point in the same direction. In the *Made in Holland* series published annually by Deloitte, the conclusion is drawn that Dutch firms have plans to relocate production as well as R&D activities outside of the Netherland (see Deloitte & Touche, 2002, 2003, 2004; Deloitte, 2005 and 2006). Also FME/CWM (2003) concludes that R&D and knowledge will follow the relocation process of production activities toward emerging markets, such as China, India and Central and Eastern Europe and in a more recent news paper article a Dutch professor in the field of innovation management feared this scenario as well.[44] On the other hand, some positive observations can be made as well, such as Philips' investments in the high-tech campus in Eindhoven. Furthermore, a report by the AWT (2006) argues that R&D has not been relocated abroad on a large scale, nor do large knowledge-intensive multinationals have the intension to do so.

These conflicting signals raises some puzzling questions such as: 'Are (multinational) companies in the Netherlands shifting their R&D activities abroad?', 'Is the innovative capacity of a country affected negatively if (multinational) firms relocate their R&D activities to foreign countries?' and 'Are foreign firms also relocating their R&D activities to the Netherlands?'. This chapter aims to address these questions. We combine a macroeconomic perspective with a firm-level perspective. This combination of perspectives enables us to move beyond a more general description on either level and to gain a deeper understanding of the driving forces of R&D and how it is organised in terms of physical location, as well as the consequences for

[44] See Financieele Dagblad, *Export naar China niet gemakkelijk* [Export to China is not easy], 3-10-2005.

national economies. This chapter is structured as follows. In Section 4.2 we present a macro picture of R&D in the Netherlands. Section 4.3 sketches the micro picture by examining the R&D process within firms and the managerial trade-offs to be made when organising this process. Based on a combination of the macro and micro perspective, in Section 4.4 the location choice of R&D activities is discussed. Finally, in Section 4.5 we conclude and formulate some implications for innovation policy.

4.2 R&D IN THE NETHERLANDS: A MACRO PICTURE

This section discusses a macro picture of the developments in R&D in the Netherlands. In this macro section we consecutively deal with the following issues. First of all, we will look at the development of R&D in the Netherlands and with it the question to what extent the Netherlands lags behind other countries. Subsequently, we look in further detail at the seven largest R&D companies in the Netherlands, the so-called 'Big Seven'[45], and their R&D strategy. This section is finished with a description of the internationalisation process of R&D.

4.2.1 Development of R&D in the Netherlands

Public and private R&D are of great importance for the productivity development of countries (Chapters 3 and 9 of this dissertation). An indicative calculation in Chapter 3 illustrates that R&D is responsible for 40% of the productivity growth in the Netherlands between 1990 and 2000. Furthermore, conducting R&D enables the absorption of foreign knowledge spillovers (Cohen and Levinthal, 1989).

In the last decade, the total R&D intensity, both public and private, in the Netherlands rose from to 7.3 billion euro in 1995 to 8.3 billion in 2005 (OECD, Main Science and Technology Indicator, 2007/2).[46] As a percentage of GDP, total R&D expenditure decreased from 1.97% in 1995 to 1.73% in 2005. This drop in total R&D intensity is especially due to a decline of public R&D intensity from 0.92% in 1995 to 0.75% in 2004, although the public R&D intensity in the Netherlands is still somewhat higher than the international average (0.66% in the EU15 as well as the OECD). The private R&D intensity in the Netherlands remained fairly stable of time (see Figure 4.1), but the level is substantially below the international average. The Dutch R&D intensity in 2005 amounts to 1.02% compared to 1.21% in the EU15 and 1.59% in the OECD (in 2004).

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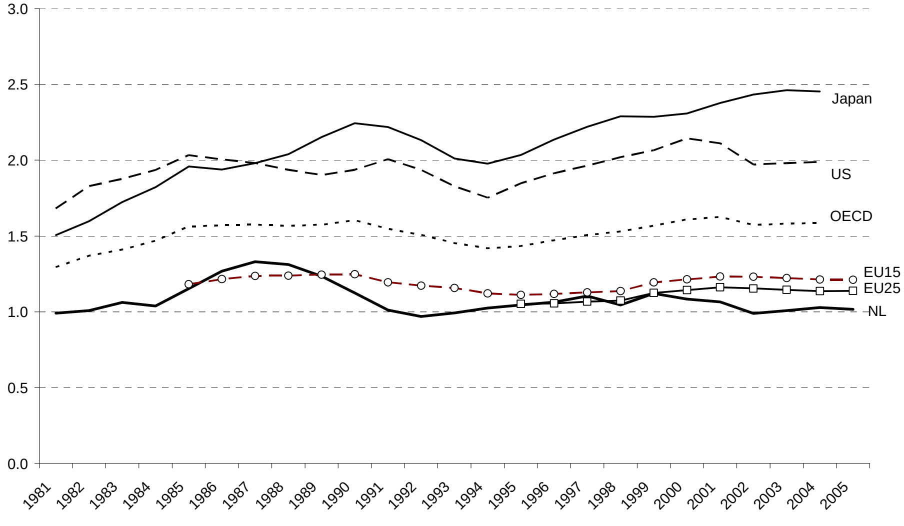
[45] Philips has spun off its semi-conductor branche in 2006. The spin-off company NXP continued the manufacturing of advanced technology systems for the semiconductor industry. NXP conducts approximately 400 million euros on R&D annually. In 2006, the Netherlands thus has eight large knowledge-intensive R&D companies and from 2006 onwards it is more appropriate to speak of the 'Big Eight'.

[46] Expressed in constant prices of 2000.

Figure 4.1 Corporate R&D expenditure by major OECD countries and the Netherlands (as a percentage of GDP), 1981-2005



Source: OECD, Main Science and Technology Indicators, 2006/2, Paris.

The question is why Dutch private R&D is lagging behind other countries.[47] One could think of a number of (non-exhaustive) explanations.

- The first reason is the Dutch sector composition. The argumentation is that Dutch firms are strongly active in R&D extensive sectors when compared to other countries. Verspagen and Hollanders (1998) analysed the differences between the Dutch R&D intensity and the average R&D intensity in a group of reference countries. Their research showed that almost half of the lagging Dutch R&D intensity can be explained by the sector structure. The strong negative contribution of the sector composition effect to the Dutch private R&D shortfall is confirmed by Ruiter (2002) and Erken *et al.* (2006, see Chapter 5).
- Another reason that is mentioned is the small scale of the Netherlands (see, for instance, Snijders, 1998). Verspagen and Hollanders (1998) demonstrate, however, that this is a 'myth': other small countries such as Sweden and Finland clearly show a high R&D intensity from an international point of view (2.93% and 2.48% in 2005 respectively).
- A third explanation is that the link between firms and knowledge institutions in the Netherlands is thought to be inadequate. This could have a restraining influence on the diffusion of knowledge throughout the Dutch economy, which, in consequence, could retain firms from undertaking (more) R&D. Statistics, however, show that the collaboration

[47] In Chapter 5 we more thoroughly examine why Dutch corporate R&D lags behind the international OECD average.

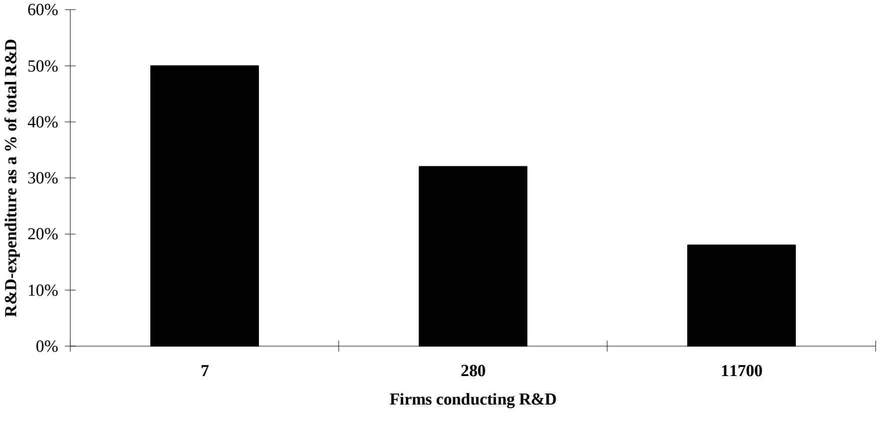
between firms and public knowledge institutions in the Netherlands is relatively high by international standards (see Ministry of Economic Affairs and Ministry of Education, Culture and Science, 2006).[48] Hence, there is no indication that the link between firms and the public knowledge infrastructure is weaker in Netherlands than elsewhere.

- Finally, a reason that is often mentioned is the internationalisation of R&D. Dutch multinationals are supposedly conducting a substantial (and increasing) proportion of their R&D abroad. In addition, the Netherlands is not attracting many R&D investments from abroad. On balance this would imply a net outflow of R&D. We will return to this matter in more detail later on in this section and in Section 4.4 (see also Chapter 5 where this subject is dealt with more extensively than in this chapter).

4.2.2 The Dutch Big Seven

Figure 4.2 shows the distribution of total R&D expenditure across firms in the Netherlands (this distribution is fairly constant over time).

Figure 4.2 Distribution of the private R&D expenditure across firms



Source: Ministry of Economic Affairs, data provided by Statistics Netherlands and CPB Netherlands Bureau of Economic Policy Analysis.

The percentages in Figure 4.2 are indicative. Seven companies undertake 50% of total private R&D in the Netherlands (see footnote 45). These seven companies are usually referred to as the ‘*Big Seven*’. The next group consists of 280 firms that account for 32% of total Dutch private

48 A substantial share of the R&D performed by research institutes in the Netherlands, such as TNO and the Large Technological Institutes, is financed by industry: 16.2% (2004) versus 5.9% in the EU15/EU25 and 2.7% in the OECD. The percentage of R&D expenditure in the higher education sector financed by the business enterprise sector is on par with the international average: 6.8% (2004) versus 6.6% in the EU15 and 6.1% in the OECD.

R&D expenditure. Finally, 11,700 firms (± 6,000 in manufacturing and ± 5,700 in services) undertake the remaining 18% of the total private R&D in the Netherlands. Since the Big Seven account for the lion's share of the total Dutch R&D, these companies will be examined more extensively.

The Big Seven consists of Philips, Akzo Nobel, ASML, DSM, Shell, Unilever and Océ and conducts about 50% of all private R&D activities in the Netherlands.[49] The skewed distribution of corporate R&D in the Netherlands is not exceptional when compared to other (small) countries. In countries such as Sweden, Switzerland and Germany a small number of firms conduct a significant proportion of corporate R&D as well. For example, in Switzerland a very limited amount of companies undertake roughly two-thirds of total corporate R&D (e.g. Roche, Novartis, Syngenta, Nestlé, ABB).

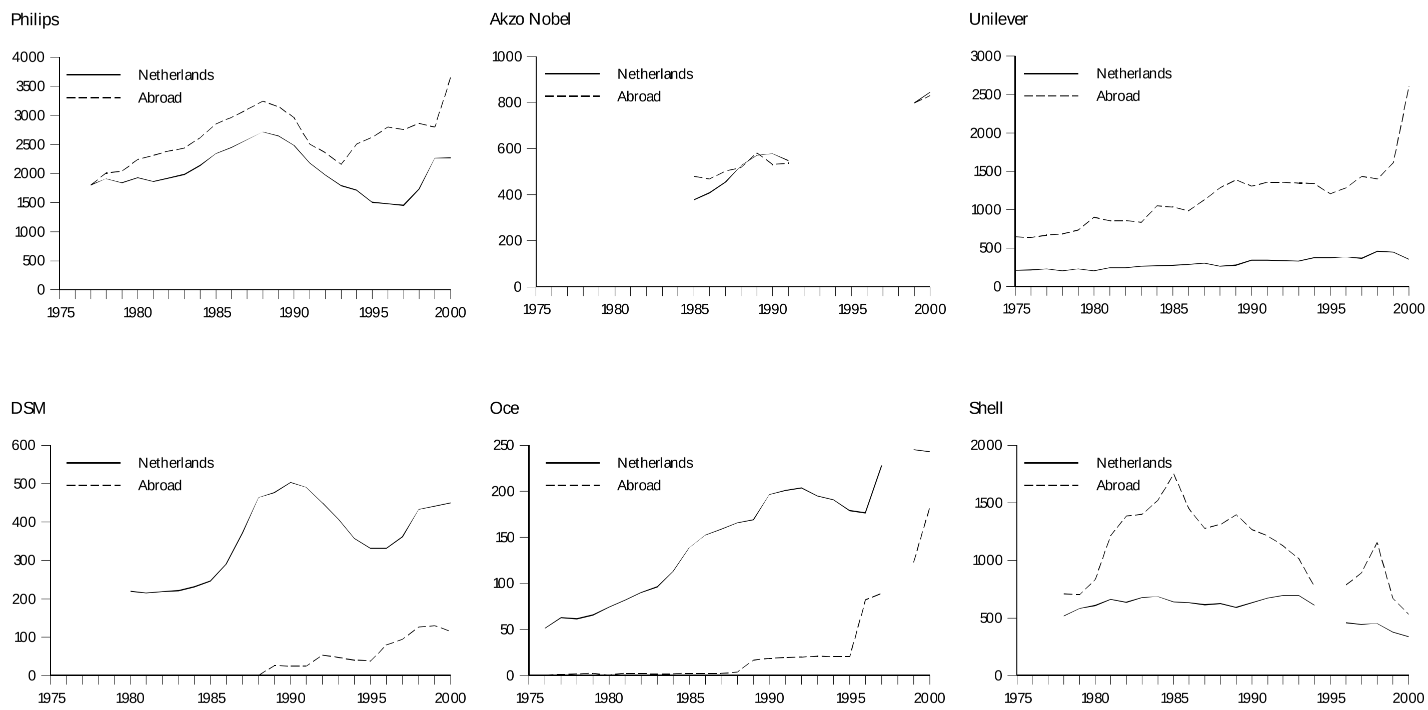
Over the years, the share of the Big Seven in total private R&D has declined (Statistics Netherlands, 2007a; CPB Netherlands Bureau of Economic Policy Analysis, 2001). Three reasons can be put forward for this decline. First of all, the share of firms with 10-49 employees tripled between 1995-2005 (Statistics Netherlands, 2007a). Secondly, several service sectors including banks, the wholesale and retail industry and engineering firms in the business services sector have begun undertaking more R&D (Cornet and Rensman, 2001).[50] Thirdly, some multinationals have spun off divisions that are now continuing as smaller R&D firms. In the past Philips has spun off AT&T/Lucent, Neways Electronics, Atos Origin, Solvay Duphar, ASML and more recently NXP (which now belongs to the eight biggest Dutch R&D firms, see footnote 45). Akzo Nobel sold their pharmaceutical branche (Organon) to Schering-Plough in November 2007 and DSM sold their petrochemical division to Sabic.

Figure 4.3 illustrates the development of R&D expenditure of the Big Seven over the period 1977-2000. In Chapter 8 of this dissertation the trend from 2000 until 2006 is sketched. Figure 4.3 shows that the share of R&D in the Netherlands has decreased at some companies such as Unilever. This decrease is a relative effect, which can be attributes to the expansion of foreign R&D activities of these firms, instead of a downsizing of R&D activities in the Netherlands (Cornet and Rensman, 2001).

49 See Technische Weekblad, *Special: R&D in cijfers* [R&D in figures], 31-03-2007; Department for Business Enterprise & Regulatory Reform, *The 2007 R&D Scoreboard. The top 850 UK and 1250 global companies by R&D investment*, http://www.innovation.gov.uk/downloads/2007_rd_scoreboard_analysis.pdf and European Commission, *The 2007 EU industrial R&D investment scoreboard*, Brussels, http://iri.jrc.ec.europa.eu/research/scoreboard_2007.htm.

50 To some extent this is an optical effect, since the R&D of services companies is better measured nowadays.

Figure 4.3 Foreign and domestic R&D expenditure of the Big Seven in millions of guilders (ASML missing)

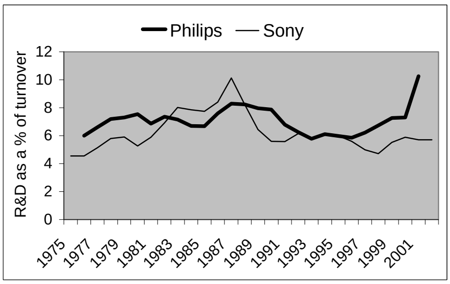


Source: Cornet and Rensman, 2001.

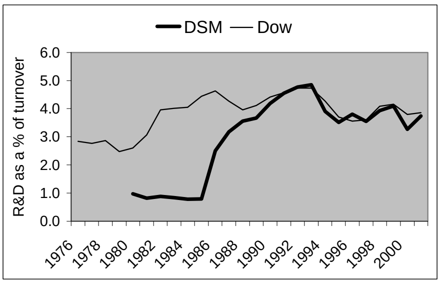
Figure 4.4 compares the R&D intensity of four Big Seven companies with a major competitor. Although the amount and trends may vary between industries, the extent of corporate R&D expenditure within the same industry shows roughly the same pattern. There are two explanations for this. One explanation is that the amount of R&D expenditure is particularly determined by what competitors do. Firms pursue such a strategy because they are anxious to lose their competitive advantage. If a major competitor conducts more R&D, this provides an incentive not to stay behind. The reverse also holds: if a business reduces its R&D activities, others follow suit in order to control costs. After all, R&D is a significant cost item that reduces profits in the short term.

Figure 4.4 Benchmark of Big Seven with major foreign competitors

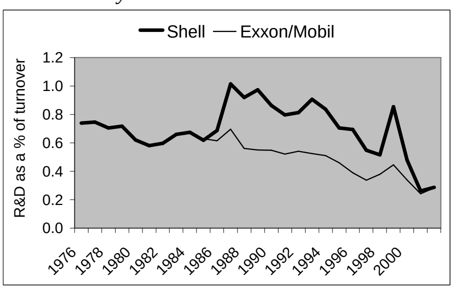
R&D intensity Philips and Sony



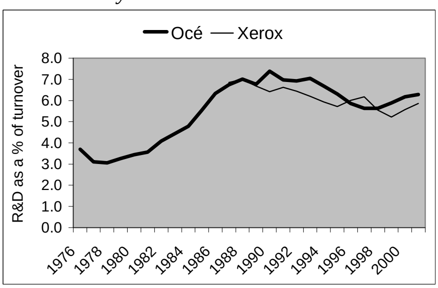
R&D intensity DSM and Dow



R&D intensity Shell and Exxon/Mobil



R&D intensity Océ and Xerox



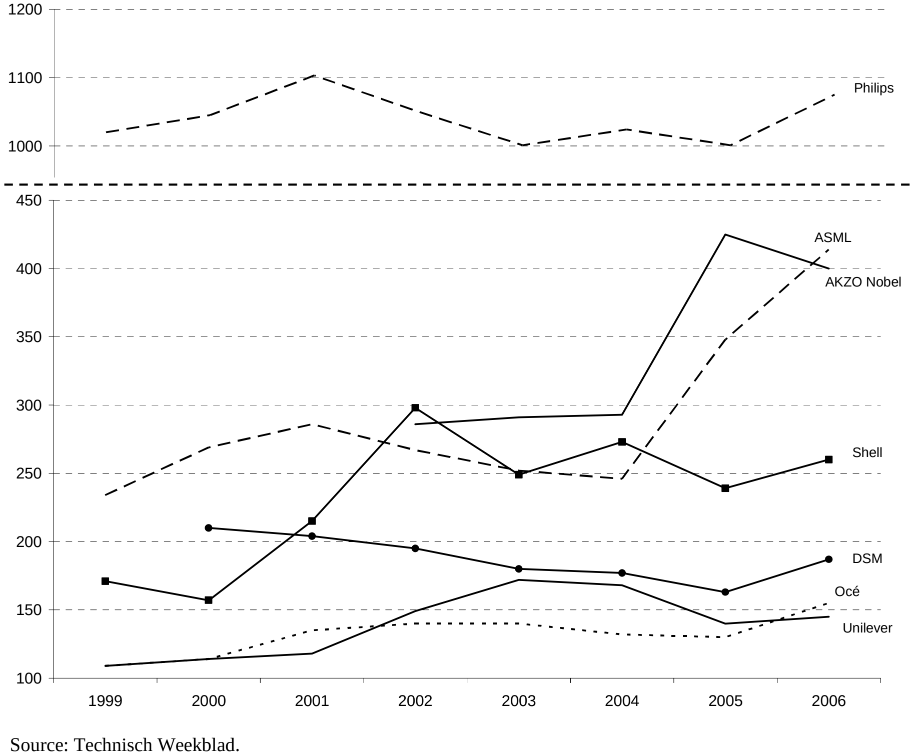
Source: Minne and Verbruggen, 2002.

A second explanation is that firms usually have common expectations of the future regarding the opportunities and risks of potential areas of technology. Firms themselves also claim that they follow the market and this leads to the observation that all firms follow roughly the same pattern. These findings are consistent with strategic management literature: firms competing in the same industry tend to develop homogenous competitive strategies with regard to investments in technology and marketing (Mauri and Michaels, 1998). It is also consistent with institutional theory that managers will incline to reduce gaps with competitors in order to gain legitimacy in the eyes of investors and other stakeholders (DiMaggio and Powell, 1983).

4.2.3 Internationalisation of R&D

To decide whether Dutch R&D intensity is being downsized by the internationalisation of R&D, one has to look at two different aspects: the inflow and the outflow of R&D investments. There are no macro figures on outward R&D investments for the Netherlands. However, Figure 4.3 gives credibility to the fact that outward R&D investments of large multinationals are not at the expense of the R&D conducted at the home base. Figure 4.5 shows R&D expenditure of Dutch MNOs at the home base for a recent period (see also Chapter 8). Domestic R&D for each firm shows a relatively stable or increasing trend, which gives an indication that MNOs did not relocate large parts of their R&D abroad.

Figure 4.5 Domestic R&D expenditure of large MNOs, millions of euros, 1999-2006

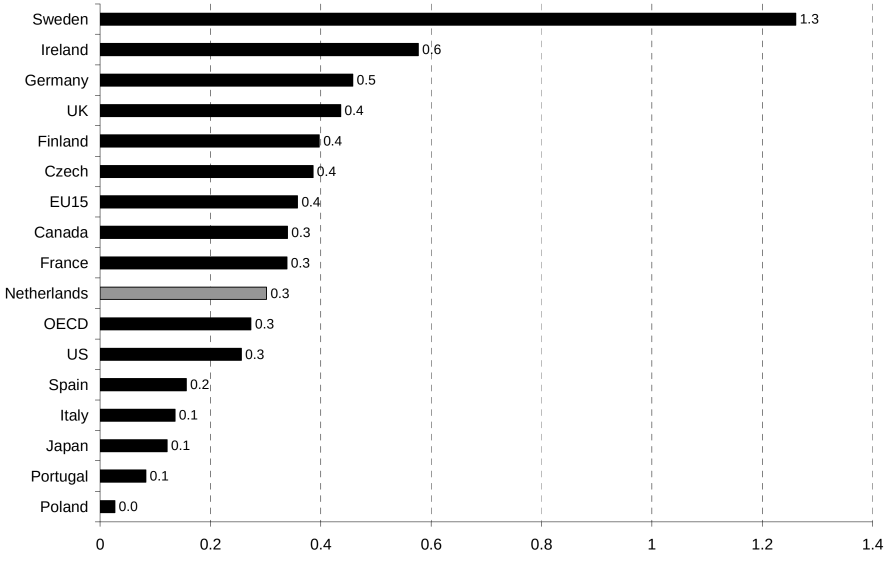


Source: Technisch Weekblad.

Indeed, Cornet and Rensman (2001) argue that there is no proof for (large-scale) relocation of R&D from the Netherlands to other countries. In a more recent study by the AWT (2006), the same conclusion is drawn. Foreign firms that took over Dutch R&D facilities or R&D firms continued these activities, as well as the location of the facility.[51] In case of acquisitions, R&D is not being relocated and there is ‘only’ a change of ownership. Furthermore, new foreign R&D activities by major Dutch companies (e.g. through the acquisition of R&D intensive foreign firms) are usually complementary to the existing R&D activities in the Netherlands and do not go at their expense (see also Patel and Vega, 1999).

The Activities of Foreign Affiliated (AFA) Database from the OECD opens up possibilities to monitor inward R&D investments by foreign firms. Figure 4.6 shows the inward R&D investments (as a percentage of GDP) in 2004. Sweden, Ireland and Germany in particular attract much R&D. In contrast, Poland, Portugal and Japan attract relatively little foreign R&D. Expressed in relation to GDP, foreign R&D investments in the Netherlands are on par with the international average.

Figure 4.6 Inward R&D expenditure as a percentage of GDP, 2004



Source: calculations of the Ministry of Economic Affairs, based on the AFA database, OECD Economic Outlook database no. 82 and OECD Main Science and Technology Indicators.

[51] There is some empirical support that foreign firms contribute equally or more to the Dutch economy than national firms (see Jaffe *et al*., 1993; Berenschot, 2007). From a policy point of view, there is little argumentation to treat foreign firms differently than Dutch firms.

However, the position of each country on international R&D investments should be corrected for the openness of an economy (see Chapter 5 for argumentation). In this case, the Dutch position on the acquisition of foreign R&D is much less positive (see Erken *et al*., 2006; OECD, 2005). If an adjustment for the openness is made, the inward R&D investments in Netherlands are clearly lagging behind the international average and countries like the UK, Sweden and Ireland in particular. In Chapters 5 and 8 we will pay more attention to the relationship between trade openness and the acquisition of foreign R&D investments.

In sum, we can conclude that the Netherlands is not confronted with a structural outflow of R&D to foreign countries. There seems to be a problem in the Netherlands, however, concerning the attraction of foreign R&D investments. The main question is how foreign firms perceive the Netherlands when it comes to setting up their R&D in a country. More in general, what factors induce firms to locate their R&D somewhere? We will return to these matters in more detail in Section 4.4 and Chapter 7 of this dissertation. Before doing so, we first turn to the micro level of firms. Indeed, the figures presented in this section are merely of a descriptive nature and do not allow us to judge how the observed trends in R&D expenditure should be interpreted. Does this picture reflect a positive situation or perhaps a more negative one? To answer this question, we need to descent to a lower level of aggregation and understand which decisions and trade-offs firms make with regard to the organisation and the associated locational aspects of the R&D process.

4.3 ORGANISATION OF R&D: A MICRO PICTURE

R&D is discussed from a micro-level perspective in this section, i.e. the way that the R&D function is organised within firms. For this purpose, we consider briefly the changes in the external context of the R&D function. Subsequently, we will discuss the way the R&D function is organised and the considerations that are being made. Next, we will deal with a number of recent as well as expected trends in the organisation of R&D. We finish this section with a resumé and the potential role of the government.

4.3.1 Context of R&D and innovation

There are a number of exogenous trends which force R&D firms to reconsider their R&D strategy. First, technologies are slowly but surely becoming more science-based, i.e. their origin is increasingly found in science, and technology is taking on a multidisciplinary character (Meyer-Krahmer and Reger, 1999). In addition, there is an increasing globalisation of markets and technology supply (e.g. Athreye and Cantwell, 2007), a steady rise in the power and versatility of ICT (e.g. Vicente and Lopéz, 2006), and networking is increasingly important as a business model (Chesbrough, 2003). On the demand side, firms are confronted with an increasing focus on shareholder value, further individualisation of customer wishes and growing concern about sustainability (Tidd *et al.*, 2005). To anticipate these developments the term ‘5th

generation R&D' is often used. This concerns the integration of a number of different types of technology in such a way that different customer wishes can be responded to quickly in a targeted and flexible way (Rothwell, 1992).

The consequence of these developments for firms is that they are increasingly being confronted with a new strategic question: *how to increase the speed and creativity of R&D (and the innovation process)*. Indeed, because of the growing intense of global competition, a faster diffusion of more complex technology and shifting preferences on the demand side, product life cycles of companies have shortened drastically inducing companies to innovate more quickly and develop products and services more efficiently (OECD, 2008a). The question how to organise the R&D process is derived from this: all organisational decisions must ultimately result in a faster production of new (or preferably: the newest) ideas, products and processes.

4.3.2 Organisation of the R&D function

Literature on the organisation of the R&D function is straightforward about one thing: there is no such thing as the best organisational structure for R&D and innovation (Zander, 1999; Volberda, 1998; Tidd *et al.*, 2005). Depending on the type of industry, the type of business, the type of innovation and the strategic objectives that have been set, firms will regularly (have to) modify the way their R&D and innovation function is organised. For this reason, it does not make much sense to elaborate on the most recent trends for each individual large R&D company. However, it is useful to describe in general terms what assessments are being made and how, in response to this, the R&D function can be organised as optimally as possible.

Research by Tidd *et al.* (2005) and Jacobs and Waalkens (2001) shows that the choice for the best organisational form of R&D is based on four organisational dimensions:

1. 'technology push' versus 'market pull';
2. centralisation versus decentralisation;
3. concentration within a country or distributed internationally;
4. internal versus external acquisition of knowledge.

'Technology push' versus 'market pull'

To what extent R&D is technology-driven or more demand-driven depends on the type of industry. Both forces play a role in a mix that varies, depending on the type of innovation pattern that is dominant in a particular sector (Pavitt, 1984; Romijn and Albaladejo, 2002; Kaufmann and Tödtling, 2001). Below, a taxanomy of different types of industries.

- Science-based industries:
  - ⇒ strong emphasis on (scientific) research into new, technological products
  - ⇒ Akzo Pharma, DSM Biologics, Philips Electronics, Unilever (food)

- Scale-intensive industries
  - ⇒ predominantly technology-driven process innovations and incremental product innovations
  - ⇒ DSM (chemicals), Shell (chemicals), Unilever (detergents), KPN, Corus
- Specialised equipment industries
  - ⇒ process innovations and product innovations, close collaboration with customers/outsourcers, aimed at (parts of) complex systems such as machines and systems
  - ⇒ ASML, Océ, Stork, Lucent, Ericsson
- Supplier-dominated industries
  - ⇒ particularly the adoption of process innovations developed by suppliers such as the ICT sector
  - ⇒ Randstad, banks, insurance companies
- Information-intensive industries
  - ⇒ product innovations that are largely market-driven
  - ⇒ publishers, banks

This taxonomy is a general overview indicating to what extent R&D is technology-driven or market-driven across different industries. Of course, this classification is not carved in stone, as shifts occur in these patterns over time and each business has the freedom to make its own strategic choices.

Centralisation versus decentralisation

Within this organisational dimension a distinction is made between fundamental research (research function) and applied research (development function). As far as the *research function* is concerned, the (traditional) rule of thumb is that the more fundamental in nature the research (i.e. with a longer time perspective and further away from the market), the more centralised. The reasons for this are economies of scale, the need to be close to the head office, and the desire to keep strategic knowledge within the business (Fors, 1998). However, fundamental research will be more decentralised when a business has a more diverse range of parts with only limited synergy. It is significant to understand that the market drives fundamental research more strongly than in the past. This is a consequence of the increasing importance of shareholder value, and with it the more stringent requirements on return from R&D investments (Jacobs and Waalkens, 2001; Minne and Rensman, 2001). Firms try to satisfy these return requirements on the one hand by allowing divisions to take initiative on how research should develop, and on the other hand through drastic acceleration of product development. In this way, more emphasis is put on research concerning customer wishes, and less on supply-driven (fundamental) research that focuses on potential customers and markets (Minne and Rensman, 2001). The result is that, in spite of the fact that firms do not publish information on the share of their fundamental research, the share of fundamental research in the total amount of R&D is thought to be small at present (Minne and Verbruggen, 2002).[52] Nevertheless, companies stress the importance of fundamental research as a foundation for innovation (Minne and Rensman, 2001). This is evident, for example, from the increasing amount of fundamental research being outsourced to universities and knowledge institutions, as well as the emerging 'second' knowledge infrastructure (i.e. an increasing amount of R&D outsoruced to business service providers).

As far as the centralisation/decentralisation of the *development function* is concerned, the determining factor to conduct R&D decentralised is when modifications to products and processes – in order to fit local market circumstances – is a critical factor for success. Usually, it involves incremental modifications to centrally developed products. If there is no need for this, and if there are economies of scale in research, centralisation of the development function will be preferred (Patel and Vega, 1999).

Concentration within a single country or distributed internationally

To some extent this organisational dimension is related to the previous one, although this dimension relates above all to the geographical distribution of R&D. Here too, a distinction is made between the development function and the research function.

Generally speaking, R&D conducted abroad regards the *development function*. It mainly reflects the need, as already discussed, to be close to local markets ('market pull'). Since the driving force of the development function is the sale of core products, the development function concentrates largely on those areas of technology in which the business has a competitive advantage. Griffith *et al*. (2003) show that in the UK on average 46% of the most applied type of R&D is co-located with production compared to 42% of all R&D done in-house. This explains why, traditionally speaking, R&D activities are not undertaken abroad very often simply to compensate for weaknesses at the home base. There must be a link to the strengths at the home base (Patel and Vega, 1999; Fors, 1998). From the mid-1990s onwards, however, a change can be observed in the above-described pattern, which concerns the research function in particular (Le Bas and Sierra, 2002).

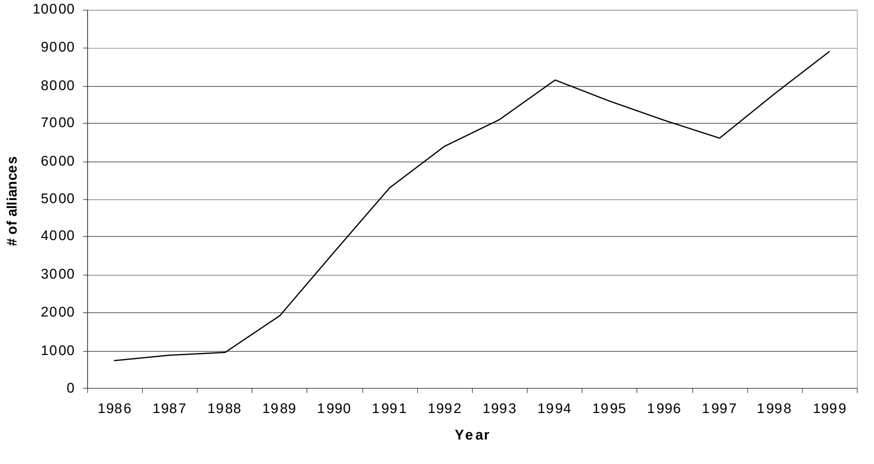
With respect to the *research function*, a new development can be observed. The increasing degree of scientification of technology and the increasing speed of change imply that firms must be able to gain the latest information fast, no matter where it is present (Meyer-Krahmer and Reger, 1999). This means that firms increasingly have (decentralised) research undertaken in countries that are specialised in the technology concerned, since it is usually at this location where the best researchers, knowledge institutions and competing colleagues are found. This development does not automatically involves relocation of large-scale research activities. The creation of small-scaled local listening posts also allows firms to pick up new knowledge fast and pass it on to the home base (Patel and Vega, 1999; Fors, 1998; Pearce, 1999). A trend

[52] The decline in fundamental R&D is also mentioned in virtually all annual reports of major R&D companies, and also follows from various interviews with corporate R&D senior executives.

associated with this is the increasing collaboration with third parties, the 4th organisational dimension.

Internal versus external knowledge acquisition
The first three organisational dimensions consider R&D predominantly from an internal perspective. For many years this was the generally prevailing adage: R&D should take place behind firmly closed doors and was considered the main driving force of innovation in a vertically-integrated innovation process characterized by a high degree of specialisation and autonomy of R&D professionals (see Roussel *et al.*, 1991; Lam, 2000). This gradually changed during the 1990s as firms came to realise that it was becoming increasingly difficult and costly to (continue to) excel in a range of different areas. Chesbrough (2003) mentions reasons behind the increasing desire to search for parties with complementary expertise in order to get quick access to different technologies and knowledge: the increasing global competition, the resulting shortening of product life cycles, the increasing complexity of new technologies and knowledge, the increasing costs of innovation, the increasing supply and mobility of researchers and the increasing supply of venture capital.

Figure 4.7 Number of strategic technology alliances each year (1986-1999)



Source: De Man and Duysters, 2003.

These factors enhance knowledge diffusion as well as possibilities to develop knowledge (on a smaller scale). Firms are conscious that the chance that important innovations in their field of competence will be developed outside of the firm is considerable. As a result, many firms increasingly start to acquire their knowledge from external sources and networks. Strategic alliances are one form of acquiring external knowledge.[53] Figure 4.7 shows the rise in the number of strategic technological alliances.

Strategic alliances focus on achieving synergy benefits through the technological complementation of two or more parties. In this respect, strategic alliances are a good way of gaining (decentralised) access to external resources, knowledge and crucial information for developing productive and innovative activities (e.g. Edquist, 1997; Kauffman and Tödtling, 2001; Romijn and Albaladejo, 2002). In addition, alliances have the advantage of limiting the risk of R&D and innovation and increasing its speed. Various international research projects in the field of strategic alliances have shown that there is a clear positive connection with innovative success (e.g. Morris and Sexton, 1996; De Man and Duysters, 2003; Heidemann Lassen, 2007; Antoncic and Prodan, 2008). In addition, it is evident that the effect of strategic alliances on innovation becomes higher the more intensive the collaboration becomes (i.e. the higher the degree of mutual dependency). It is not surprising that strategic alliances have increased dramatically in the past few years (Tidd *et al.*, 2005, p. 306). Forms of collaboration can be brought about in several ways. Think, for instance, of the use of licences, R&D contracts, joint ventures and even mutual research facilities.

A striking form of collaboration that has arisen in the last few years is *corporate venturing* (Christensen, 2000). There are several motives for establishing corporate ventures, such as the growth of a business, introduce pressure on internal suppliers, divest non-core activities, diversy the business, spread the risk and costs of product development and the development of new technological or market competences (Tidd and Taurins, 1999). In relation to innovation, corporate venturing can be successful to encourage more radical innovations that would not flourish in the more incremental innovation logic of the parent company. In addition, corporate venturing can also be successful to develop new technology, because more risks can be taken without alarming shareholders, while access is still being obtained to innovative ideas and plans.

In many cases the innovative venture (once again) becomes part of the parent company (or is taken over by one of the shareholders) if the innovation proves to be profitable.[54] At the same time, many initiatives that do not live up to their promises are ended. The advantage of corporate venturing is that access becomes possible to innovative ideas outside the company's existing knowledge network, which enables more creative output to be generated faster (Darroch *et al*., 2005; Grandori, 1999). Companies such as Shell and DSM have had positive experiences with this.

Alternatives to alliances are mergers and take-overs, where existing knowledge is internalised by an organisation. Research by De Man and Duysters (2003) shows that firms choose the

[53] Besides collaboration as one form of external knowledge acquisition, one could also think of the outsourcing of research.

[54] This trend is also referred to as a shift from R&D to A&D (acquisition and development).

merger option to create economies of scale in R&D, thus increasing the concentration of R&D. The biggest disadvantage of mergers and take-overs is that they reduce attention for innovation in the short-term, since the post-merger integration of firms demands a great deal of management attention. In addition, there is the risk that organisational cultures will not dovetail well with each other, making it difficult to achieve the intended synergy effect (De Man and Duysters, 2003). This problem does not exist with strategic alliances.

4.3.3 Trends in the organisation of R&D

Gassmann and Von Zedtwitz (1999) discuss five trends that relate to the changes in the organisation of the R&D function (see Figure 4.8). A first trend is that firms with a centralised R&D function begin to adjust more and more to the international environment. Kaufmann and Tödtling (2001) and Malecki (1997) confirm that innovation increasingly becomes an evolutionary, non-linear, and interactive process between the firm and its environment. It becomes increasingly clear that it is necessary to adjust to both local and international market needs. This implies a shift from an ethnocentric direction to a geocentric R&D organisation (trend 1 in Figure 4.8).

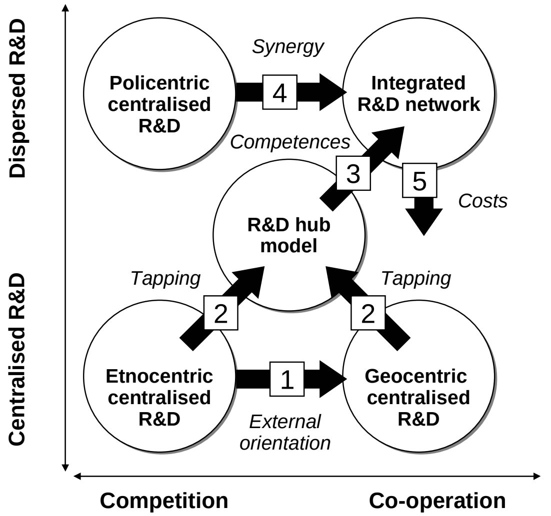
A second development is the increase in the number of listening posts, as already discussed, at locations where state-of-the-art expertise is to be found. These listening posts will become the most important sources of new knowledge. This is trend 2 in Figure 4.8 towards the R&D hub model.

A third trend is that a strict control over the business's own international R&D organisation is reduced in favour of more autonomy and empowerment of decentralised R&D units. The significance of decentralised R&D units increases and their flexibility and creativity are enhanced. In this respect it is important for information to be exchanged between these separate units without restrains. The increasing importance of co-ordination leads to more integrated R&D networks (trend 3 in Figure 4.8).

The fourth development refers to an increasing degree of work distribution between the various R&D units within a firm. *Centres of excellence* are created, focusing on specific areas and reducing the risk of duplication of R&D (trend 4 in Figure 4.8).

The fifth and final trend is the increasing significance of an integrated R&D network within the business, in which there is optimal *cost-effective* working and *co-ordination* between the various units. In a certain sense this is recentralisation, particularly when the number of individual R&D units is reduced to a limited number of centres of excellence. The above-mentioned trends are an extension of each other, and at the same time show the field of tension that continually exists when trying to find the best possible mix of the four organisational dimensions as discussed before.

Figure 4.8 Developments in corporate R&D planning policy of firms



Source: Gassman and Von Zedtwitz, 1999.

Two more recent trends in the organisation of R&D and innovation are the ‘open innovation’ model (Chesbrough, 2003, 2006; Chesbrough *et al.*, 2006) and the model of ‘user-driven’ innovation (Von Hippel, 2005). The open innovation model relates to the increasing rate of external knowledge acquisition addressed in Section 4.3.2. Chesbrough (2003, p. XXIV) refers to the idea of open innovation as follows: *“firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology”*. Even the sharpest leading edge companies can no longer survive on their own R&D efforts, but must open up their networks and collaborate with others. By opening up the High Tech Campus in Eindhoven, Philips, for example, has taken offensive step to inplement the open innovation model. The OECD (2008a) stresses that companies themselves view open innovation as close collaboration with external partners, i.e. customers, consumers, researchers or other people that may have relevant knowledge for their company. In line with this definition Von Hippel (2005) introduced the term ‘user-driven innovation’. This means that in certain branches of the economy ‘lead users’ constitute the main source of innovation, e.g. sports equipment, health products and personal care, and computer applications. Involvement of ‘lead users’ in the innovation process requires a different way of organising the R&D and innovation process. Un and Price (2007) argue that: *“to provide people with truly meaningful solutions, rather than technological possibilities, the needs of those people need to be taken into account from the earliest phases of development onwards”*. Although open innovation as a trend has implications for policy (see als Section 4.5), the OECD (2008a, 2008b) emphasizes that ‘open innovation' is not completely new. The growing attention on open innovation reflects primarily a greater awareness of innovative activities (technological and non-technological) across firm boundaries with a more balanced importance given to internal and external sources of innovation (OECD, 2008a, 2008b).

4.3.4 Resumé

The strategic question confronting firms when organising their R&D function is: how to increase the speed and creativity of the R&D and innovation process. For this purpose, four organisational dimensions are considered:

- To what extent R&D is technology-driven or market-driven is initially determined by the industry in which a firm is active.
- In considering the centralised/decentralised and home base/international dimensions, traditionally it is the development function in particular that takes place at a decentralised level depending on the local market conditions, and is distributed across a number of different countries.
- We have recently seen that the research function can also be more decentralised, through developing activities in other countries (in the form of listening post for instance) where state-of-the-art knowledge is available.
- External knowledge acquisition is increasingly used by way of strategic alliances, open innovation networks and the involvement of 'lead users'.

As already stated, it is difficult to recognise individual trends on a micro level perspective, because industries and businesses differ to a large extent. One trend, however, that seems to cross industry boundaries is the increasing importance of state-of-the-art knowledge and the ability to gain it fast and directly, wherever it is located around the globe. This also explains the emergence of the open innovation model and increasing usage of 'lead users' as sources of innovation.

4.3.5 Potential role for government

Viewed from a government's perspective, the first two organisational dimensions ('technology push' versus 'market pull' and centralisation versus decentralisation) can largely be considered exogenous. As already mentioned, these two dimensions are determined above all by the type of sector (its dominant innovation pattern) and the strategic choices of a firm. The government could possibly influence the other two organisational dimensions: the choice of location as well as the degree of collaboration with third parties. With regard to this latter dimension, the link between firms and knowledge institutions in the Netherlands does not seem to be inadequate (see also Section 4.2.1). We therefore will not further elaborate on this. With regard to firms' choices of their R&D location, we have indications that the Netherlands is lagging behind other countries in attracting knowledge-intensive firms from abroad. It is worthwhile to further analyse why the Netherlands has this relatively weak position. This topic is picked up in the next section, but is examined more systematically in Chapter 5 of this dissertation.

4.4 CHOICE OF LOCATION FOR R&D

In Section 4.2 on the macro level, we mentioned that internationalisation of R&D could be a possible explanation for the shortfall of the Dutch private R&D intensity compared to the OECD average. In Section 4.3 on the firm level, we made clear that the choice of location for R&D is an organisational dimension that could possibly be influenced by the government. These two observations are input for further analysis in this section regarding the choice of location for R&D. For this purpose we make a distinction between centralised R&D locations at the home base, international R&D locations and the climate for establishing a business in the Netherlands. We finish this section with a summary.

4.4.1 Home-base R&D locations

The location of the R&D base of large multinationals is basically determined by *historic path-dependency* (Gassmann and Von Zedtwitz, 1999; Cornet and Rensman, 2001; Cantwell and Kosmopoulou, 2003; Cantwell, 2000). This conclusion is in line with evidence at the macro level: existing laboratories in the Netherlands are not readily relocated abroad. Evidently, R&D is (still) strongly rooted in the environment where it historically emerged. There are indications in the literature as to the (possible) reasons for this. Goedegebuure (2000) argues that R&D employees usually build up a local network with suppliers and knowledge institutions for which geographical proximity is important, particularly with regard to the transfer of tacit (‘soft’) knowledge and skills (see also Nelson and Winter, 1982; Audretsch and Feldman, 2004; Cantwell and Iammarino, 2003). Relocation of R&D is at the expense of this tacit knowledge exchange that is indispensable for R&D (cf. Audretsch and Feldman, 1996; Jaffe *et al.*, 1993). This opposes against the idea of ‘death of distance’ as a consequence of ICT, which supposedly would enable R&D activities to become footloose too. In other words, most firms often choose to maintain their home-base R&D at the existing location, because this allows them to benefit from economies of scale and the local networks with which their research is often closely intertwined.[55] Hence, the location of R&D is not only tied to a particular country, but also and above all to a particular region, city or town.

Feldman (1999, p. 20) argues that knowledge spillovers from science-based activities are localised and contribute to higher rates of innovation, increased entrepreneurial activity and increased productivity within geographically bounded areas. For foreign firms, the same thing generally applies: they will be more likely to choose for the Netherlands if they are already active here with a factory, distribution centre or research laboratory (Gassmann and Von

[55] This conclusion mainly seems to concern fundamental research, for which the proximity of local knowledge institutions is important. As far as the development function is concerned, a comparative assessment is made between economies of scale in research on the one hand, and the proximity to local markets on the other hand (Patel and Vega, 1999). Depending on the type of sector and naturally the business concerned, this comparative assessment will be made differently. For more market-driven innovations the geographical proximity is important (such as the food sector), while for scale- or technology-driven innovations the concentration at a single location will be the choice preferred (as in the chemical or electronics industry) (Patel and Vega, 1999).

Zedtwitz, 1999; Cornet and Rensman, 2001). As stated in Section 4.2, the macro picture confirms this: Dutch R&D activities that have been taken over, continue these activities in the Netherlands.

4.4.2 International R&D locations

Research by Kuemmerle (1997, 1999) and Le Bas and Sierra (2002) on the location of international R&D activities shows two strategies are dominant:

- *Home-base exploiting strategy*: R&D is undertaken centrally at the home base and local R&D activities are initiated in response to the necessity of adaptation to local market conditions. These R&D activities thus have a supporting function for production facilities situated overseas, and the choice of location is determined by relevant markets.
- *Home-base augmenting strategy:* R&D activities are developed at locations where there is obvious strength in the same area of technology. These new local activities are complementary to the central R&D activities and focus on increasing the knowledge base of the firm.[56]

During the 1990s the home-base augmenting strategy increased in importance (see Le Bas and Sierra, 2002; Gassmann and Von Zedtwitz, 1999). Essential for this strategy is the quality of the local knowledge environment. Determining factors in the choice of location encompass the availability of high-quality R&D personnel and the quality of the public knowledge infrastructure (Cornet and Rensman, 2001; Chapter 7 of this thesis). However, the local knowledge environment can be viewed much more broadly. Porter (1990, 1998) points to the importance of the presence of lead-users and/or specialised suppliers that can persuade firms to develop local R&D activities. These R&D activities can then bear fruit elsewhere, including the home base. Porter (1990, 1998) argues that not only these factors play a role, but also the 'innovation climate' in a broader sense, including aspects as the fiscal climate, the infrastructure and other typical macro factors for setting up a R&D facility. In addition, costs do not seem to play a decisive role in the choice of location for R&D. There are indeed indications that *quality* is the determining factor, rather than the (wage) costs of R&D (Cornet and Rensman, 2001; Patel and Vega, 1999). In Chapter 7 of this dissertation, the location factors of R&D are examined in more detail using the results of a literature review, a field study and an econometric analysis.

4.4.3 Climate for establishing R&D in the Netherlands

Several international benchmark studies demonstrate that the climate in the Netherlands for establishing R&D is sufficiently competitive compared to other OECD countries, but no more than that (see AWT, 2006; Statistics Netherlands, 2007b; Ministry of Economic Affairs and Ministry of Education, Culture and Science, 2006).

[56] Research by Le Bas and Sierra (2002) shows that small countries in particular use this strategy, such as Denmark, Norway, Switzerland and the Netherlands. Japanese firms also make extensive use of this strategy.

It is beyond the scope of this chapter to exhaustively discuss the R&D investment climate in the Netherland from an international perspective. However, we want to highlight two elements of the R&D investment climate: the availability of scientists and engineers and the position in international business climate studies.

The number of human resources in science and technology is high in the Netherlands (see Ministry of Economic Affairs and Ministry of Education, Culture and Science, 2006). However, a growing cause of concern is the quantity, in particular if we look to the future: the number science and technology graduates has been low for quite some time in the Netherlands. The scarcity of certain knowledge workers can slow down innovation processes. In addition, it may even cause Dutch firms to relocate their knowledge intensive activities abroad and discourage foreign firms to establish or continue R&D in the Netherlands (Marey *et al.,* 2002). A recent study by De Graaf *et al*. (2007) shows that – between 2003 and 2006 – the scarcity of science and engineering (S&E) personnel has increased faster than that of other personnel. The number of vacancies difficult to fulfil rose from 30% in 2003 to almost 50% in 2006 (in contrast, this number was 35% in 2006 for non-S&E personnel).[57] Future projections by De Grip and Smits (2007) illustrate that for the near future (until 2010), the annual mismatch between supply and demand will be greater for science and engineering personnel than for non-S&E personnel. The guarantee of sufficient Dutch scientist and engineers becomes even more urgent as studies show that a firm's commitment to, and performance in, innovation depends to a certain degree to the share of top management with training in science and engineering (see Scherer and Huh, 1992; Bosworth and Wilson, 1992).

Another issue that is worthwhile mentioning is that annual studies conducted by IMD, the World Economic Forum (WEF) and the Economic Intelligence Unit (EIU) show that for a number of years the Netherlands has been achieving a very high score on the competitive power of the economy and the attractiveness of doing business. However, when it concerns the attractiveness of R&D investments, the Netherlands paradoxically has a substantially lower position. The question is where exactly these differences are to be found, and how foreign R&D firms perceive the Netherlands when it comes to setting up their R&D activities in a foreign country. Closely related is the question to what extent R&D by foreign firms in the Netherlands is prompted by market considerations, induced by proximity to the European market (in relation to the development function), or by the unique knowledge that is available in the Netherlands (with respect to the research function). In other chapters of this thesis we will shed more light on the determinants of the R&D investments and the Dutch position on these determinants (Chapters 7 and 8).

[57] Shortage of scientists and engineers differs highly among sectors. More international-oriented industries have fewer problems to cope with scarcity than the economically more sheltered sectors. In the construction sector, for example, major labour shortages are expected. Here there is a great demand both for additional and replacement S&E personnel, while these vacancies cannot be filled by foreign personnel. Also, if employment conditions remain unchanged in the Netherlands, a major annual shortage of university-level mechanical and electrical engineers can be expected.

4.4.4 Resumé

Historic path-dependency provides an important explanation for the location of mulinationals' R&D at the home base. Centralised R&D at home base is largely intertwined with the environment where it operates. This explains why we do not observe major outflows of R&D towards foreign countries (see Section 4.2.3). With regard to international R&D locations, two important determinants are the availability of high-quality R&D personnel and the quality of the public knowledge infrastructure. On balance, the Netherlands occupies an average position on these determinants. This may be one of the reasons why the inward R&D investments in the Netherlands is falling behind the international average and countries like the UK, Sweden, and Ireland in particular (see also Chapter 5 and 8 of this dissertation). Foreign knowledge-intensive firms do not have a specific preference nor aversion with respect to the Netherlands. Apparently, companies are less attracted to countries that have a *good* R&D investment and only locate R&D activities in an *excellent* R&D environment (Gassmann and Von Zedtwitz, 1999; Cornet and Rensman, 2001).

4.5 DISCUSSION AND POLICY IMPLICATIONS

In this section we discuss the outcomes of our analysis outlined in this chapter and formulate some conclusions and policy implications.

4.5.1 No systematic relocation of R&D activities yet…

The development of Dutch R&D at the macro level is a fairly 'calm' one: absolute R&D expenditure rising proportionately with GDP and no systematic relocation of R&D.[58] However, underneath this relatively 'smooth surface' the situation is highly dynamic and heterogeneous. As outlined in Section 4.3, at the micro level we see increasing competition and an ongoing acceleration of product and technology cycles. For firms the most important strategic question is how to increase the speed and creativity of R&D, and the total innovation process. The way in which this is done varies considerably from industry to industry and between companies, making it difficult to identify universal trends. However, one emerging trend which seems to cross sector boundaries is the growing significance of state-of-the-art knowledge, as well as the growing importance of having *access* to such knowledge, wherever it is located around the globe. In order to create this access, many companies decide to set up local R&D activities, by means of listening posts for example.

In developing such decentralised R&D activities, the home base still continues to be very important: foreign R&D activities must complement the home country's R&D activities, taking into account that the lastmentioned activities are still dominant. The observation from the macro

[58] This does not alter the fact that the level of private R&D as a percentage of GDP in the Netherlands lags behind other countries. The private R&D intensity in the Netherlands (1.02% in 2005) is slightly lower than the EU average (1.21% in 2005) and significantly lower than the OECD average (1.59% in 2004).

perspective that Dutch companies are developing an increasing amount of R&D activity abroad can in fact be regarded as a positive sign from a firm perspective. It shows that these companies are well connected to international knowledge networks that are relevant to them. As a result, the knowledge that has been developed abroad comes back to the Netherlands through Dutch companies. Of course the reverse is also true: knowledge developed in the Netherlands finds its way abroad. This is the 'new game' that is developing ever faster in the international R&D arena. This raises the question to what extent it should be considered a matter of concern if a (large) company undertakes all of its R&D in one single country. In a globalising world, it is important for knowledge-intensive companies to tap into relevant knowledge networks around the globe in order to remain competitive in their field of competence.[59]

4.5.3 Towards policy: from 'inside-out' to 'outside-in'

As far as the internationalisation of R&D is concerned, up to now the policy discussion has largely been characterised by an 'inside-out' focus: to what extent is R&D being moved from the Netherlands to other countries? As already stated, this has not proven to be the case. Because of this one-sided view, the other side of the coin of this internationalisation trend has not been examined adequately, being the 'outside-in' focus: to what extent does the Netherlands benefit from R&D activities conducted by foreign companies? This narrow focus is illustrated by the fact that there is only limited insight into 'outside-in' knowledge flows.[60] As will be illustrated in Chapter 5, the Netherlands is lagging behind the OECD average in attracting foreign R&D investments (see also OECD, 2005). As illustrated in Section 4.4 on the location factors of R&D, this weak position can possibly be explained by the fact that the Netherlands occupies an average position on the attractiveness of its R&D investment climate. Although at first sight this does not appear to be a matter of concern, it may become a serious problem in the long term. In spite of the importance of the home base, the significance of state-of-the-art knowledge and skills is increasing further and excellent knowledge is becoming more important than nationality. This may imply that the relationship between R&D firms and their home base decreases in significance. Over what period of time and in which industries this may occur is still insufficiently clear, but it is beyond any doubt that this process is unfolding itself. As a result, it is not inconceivable that future international R&D investments will be made in only a small number of countries with a highly favourable innovative climate.

[59] An example is DSM, which undertook all its R&D activities in the Netherlands until the mid-1990s. DSM has meanwhile decided to switch from bulk chemicals to high-quality pharmaceuticals and life sciences. The latter is a knowledge-intensive business that requires a higher rate of R&D activities.

[60] These are our own findings, as well as those of Cornet and Rensman (2001) and is also evidenced by research conducted by Dalton *et al.* (1999).

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CHAPTER 5

Anatomy of private R&D expenditure: An explanation of the Dutch R&D shortfall based on empirical evidence

5.1 INTRODUCTION

Innovation is a primary driver of productivity growth (see, for instance, Baumol, 2002; Jones, 2002; Chapter 3 of this thesis). This observation is underlined by two major innovation/R&D objectives formulated by European political leaders. The first is the *Lisbon Agenda,* which expresses the EU's ambition to become the world's most dynamic and competitive knowledge-based economy by 2010 (European Council, 2000). In addition to the Lisbon Agenda, the Netherlands has the intention to become one of the best-performing knowledge-based countries in the EU by 2010. The second policy goal is the – more specific – *Barcelona Target*, in which the EU commits itself to raising R&D expenditure to 3% of GDP, two-thirds of which should be financed by the private sector (European Council, 2002). For the Netherlands and most other of the EU countries this means a sharp rise in private R&D intensity. At the same time, public R&D efforts will have to be increased substantially in the EU as a whole.

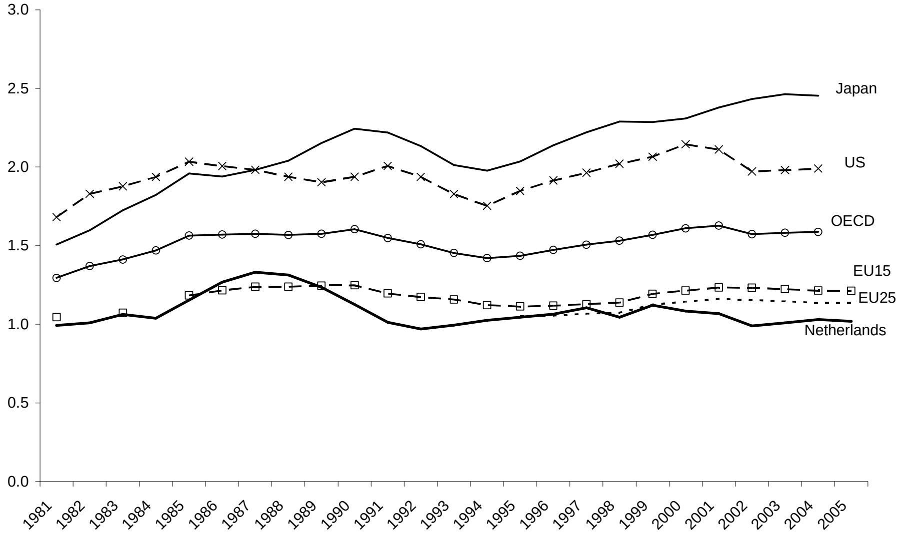
In empirical research, innovation is often represented by R&D variables. More R&D expenditure does, however, not automatically lead to more innovation. R&D is one of the input factors in the total innovation process (Acs and Audretsch, 2005; Klomp, 2001). Nevertheless, R&D is the only reliable indicator when the relationship between innovation and productivity is analysed in large time series research. The powerful explanatory strength of R&D variables in empirical research on productivity development suggests that R&D is a good indicator of innovation. Thus, subject to an efficient innovation system, R&D may be regarded as the fundamental driver of innovation.

In the Netherlands *private* R&D expenditure as a percentage of gross domestic product has been more or less constant at around 1% since the late 1970s.[61] During the 1990s, this 'R&D

[61] R&D expenditure as a percentage of Gross Domestic Product is usually referred to as the *R&D intensity*.

intensity' was consistently lower than the OECD average (see Figure 5.1). Between 1990 and 2003 private R&D expenditure in the Netherlands averaged 1.04% of GDP as opposed to 1.50% in the OECD and 1.19% in the EU15. Recent figures from the OECD Main Science and Technology Indicators (2006-2) show that private R&D intensity in the Netherlands in 2004 (of 1.03%) was falling behind the OECD average (1.59%) by 0.56 percentage points.

Figure 5.1 Private R&D expenditure in various OECD countries and the Netherlands (as a percentage of GDP), 1981-2005



Source: OECD, Main Science and Technology Indicators, 2006-2.

The importance of R&D for economic growth, the high ambitions at the European and national level, and the relatively low score of the Netherlands in private R&D all argue in favour of raising private R&D intensity in the Netherlands to a consistently higher level. Obviously, the same arguments apply to private R&D intensity in the EU as a whole. To achieve this aim, it is essential to first identify the determinants of private R&D intensity and to establish their relative importance. We shall therefore trace the factors responsible for the discrepancy between private R&D intensity in the Netherlands and the OECD average in 2001. We have chosen 2001 as a reference year, because lack of data prevents us from analysing a more recent year. In 2001 the R&D gap between the Netherlands (1.10%) and the OECD average (1.64%) was 0.54 percentage points.

As will be discussed in this chapter, the gap between private R&D intensity in the Netherlands and the OECD is due to two effects: a *sector composition effect* and an *intrinsic* effect. Both effects were negative in the Netherlands in 2001. A negative *sector composition effect* in the Netherlands compared with the OECD indicates that the share of knowledge-intensive industries in the overall economic structure of the Netherlands is below the OECD average. For instance, Dutch industry is characterised by large banking and logistics organisations, which spend relatively little on R&D.[62] An indepth analysis of the sector composition effect of the Netherlands compared to the OECD average is presented in Section 5.2.

The *intrinsic effect* is the complement of the sector composition effect and represents the within-industry effect. A negative intrinsic effect implies that companies within an industry spend less on R&D compared to their foreign peers in the same sector abroad. In Sections 5.3 to 5.6 we disentangle the negative intrinsic effect of the Netherlands. The emphasis will be on the effect of *internationalisation of R&D* (Section 5.3) and *openness of the economy* (Section 5.4), the two dominant factors in explaining the intrinsic position of the Netherlands in 2001. Of course, there are many more variables that influence R&D expenditure within countries, such as economic regulation, intellectual property rights, government funding of private R&D and financial variables. In Section 5.5 we will illustrate the methology how to determine the contribution of these factors to the R&D gap of the Netherlands. The background paper by Erken and Ruiter (2005) deals much more extensively with the impact of these other determinants. The contributions of all determinants will be taken into account in the final section (Section 5.6), where we will present an overall decomposition of the R&D shortfall in the Netherlands compared with the OECD average. In Section 5.7 this chapter is finished with some closing comments.

The available empirical material dealing with the determinants of private R&D expenditure is, however, scant and not always consistent (see, for instance, Becker and Pain, 2008). Given the fact that various empirical studies present somewhat different outcomes, quantification of the contribution of various determinants must be viewed with a certain degree of prudence. In addition, some factors are not dealt with in this chapter nor the background study by Erken and Ruiter (2005), like, for instance, culture, the availability of human capital and the size of countries. Unfortunately, the contribution of these factors to the Dutch private R&D gap is not easily determined, either because of data problems or because of contradictory empirical evidence. For instance, the impact of human capital on R&D expenditure in most empirical studies is insignificant (see Kanwar and Evenson, 2001; Reinthaler and Wolff, 2002).[63] More research is needed to examine the impact of the omitted variables on private R&D expenditure.

[62] This is, at least partly, due to historical developments (the Netherlands has a long history of trade) and its central geographical location within Europe.

[63] An insignificant effect of human capital – share of high educated persons within total population – in the study by Reinthaler and Wolff (2002) is found in a fixed effects model and a model with random effects. In estimations of a model without fixed effect the researchers do find a significant effect of human capital, which means that human capital arguably could have a positive effect on R&D in the cross-section dimension. Panel data estimations without fixed effects, however, are vulnerable to estimation bias, because of possible unobserved heterogeneity (Wooldridge, 2003, pp. 438-444; Popkowski *et al*., 1998). As a consequence, we perceive these empirical outcomes with some caution.

Nevertheless, we believe that the larger part of the most important factors of private R&D are included in this study, which enables us to give a fairly clear picture of the causes behind the observed R&D shortfall in the Netherlands in 2001.

Another limitation of the research in this chapter is that the interrelation between different determinants of corporate R&D is ignored. We feel, however, that the partial approach used in this chapter is the best methodology at hand to gain more insight into the factors that underlie differences in private R&D between countries or regions. Furthermore, the usefulness of this study is, in our opinion, not limited to the Netherlands. Although the results refer to the Dutch situation, we believe that the decomposition analysis in this study can also be applied to other countries. By linking the coefficients from the empirical literature to country-specific data (the Netherlands in our case), one can generate comparable exercises for other countries. On top of that, some new elements are dealt with in this study. In addition to existing knowledge, we shed light on endogenising the sector composition effect and provide new evidence regarding the relationship between openness of the economy and foreign R&D investments.

5.2 SECTOR COMPOSITION EFFECT

This section takes a closer look at the influence of the sector composition effect on private R&D expenditure. Van Velsen (1988) was one of the first to develop a useful methodology by studying the effect of the 'economic structure' on the difference between private R&D expenditure in the Netherlands and an average for five OECD countries based on normative and actual R&D expenditure. Later, Hollanders and Verspagen (1998 and 1999) and Ruiter (2003) conducted more extensive analyses of the impact of the sector composition on the shortfall in Dutch private R&D compared with other countries. We use the calculations from the study by Ruiter (2003) in this chapter, but have updated them with more recent data. An important new element is the attempt to endogenise the sector composition effect (Section 5.2.3). This is done by investigating to what extent the sector composition effect is influenced by a change in, amongst other factors, the actual amount of private R&D expenditure. The results are used in a simulation discussed in Section 5.2.4, which shows the potential development in the sector composition effect if the Netherlands were to gradually nullify its negative intrinsic effect over time vis-à-vis the OECD average.

5.2.1 Methodology and data

The formula used in the aforementioned studies and in this study is:

$$RDI_{NET} - RDI_{FOR} = \sum_i RDI_{FOR,i}(P_{NET,i} - P_{FOR,i}) + \sum_i P_{NET,i}(RDI_{NET,i} - RDI_{FOR,i}) \qquad (5.1)$$

where *RDI* stands for the extent of private R&D intensity (measured by expenditure on R&D as a percentage of the gross value added), *P* represents the share in value added, *i* denotes the sector, and *NET* and *FOR* respectively represent the Netherlands and the group of countries with which the Netherlands is compared (in our case the OECD average). The sector composition and the intrinsic effect are expressed as separate components in the equation. The first term after the equals sign represents the *sector composition effect*. A negative sector composition effect implies that the Netherlands has a relatively small share of R&D intensive sectors compared to the OECD average; a positive effect means the opposite. The *intrinsic effect* is the complement of the sector composition effect and represents the term after the plus in equation (5.1). A negative intrinsic effect implies that, taking the sector composition effect into account, firms in Dutch sectors spend less on private R&D compared the same sectors abroad. A positive effect indicates the opposite.

To use equation (5.1) we need data on private R&D expenditure and value added at the industry level. In this study we used data from the ANBERD and the STAN database, both from the OECD. Missing data have been added, based on data from other OECD sources.

The most significant features of the data:

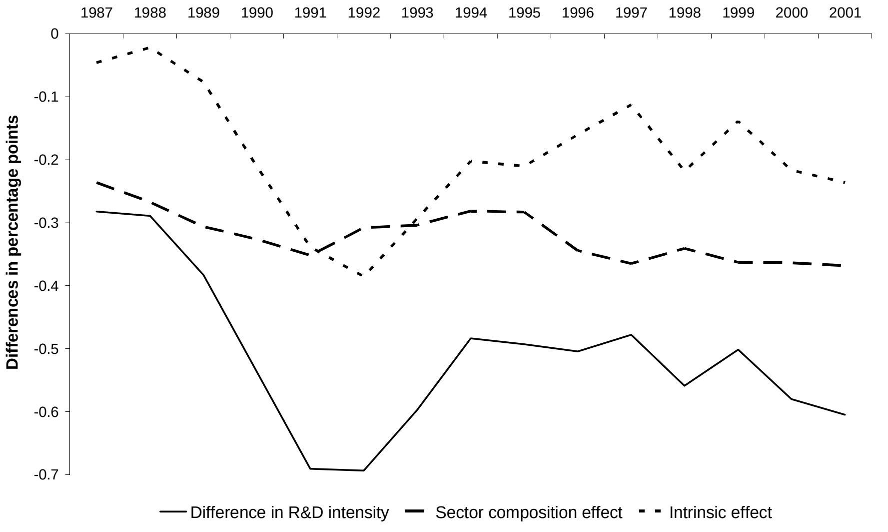
- The data cover a 15-yearly period between 1987 and 2001.
- The data encompass five main industries: the primary sector; total manufacturing; electricity, gas and water; construction; and services. Total manufacturing is divided into 18 sub sectors at 2-digit level.
- Nineteen countries were selected: Australia, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Korea, the Netherlands, Norway, Poland, Spain, Sweden, the UK and the US. There is insufficient data to include all the OECD countries in a weighted OECD average.[64] We assume that the selected countries are representative for the OECD as a whole. In reality, the OECD average is slightly lower: low R&D intensive countries, such as Greece and Portugal, have not been taken into consideration.

5.2.2 Sector composition effect over time

In this section the difference between private R&D intensity in the Netherlands and the OECD average is broken down into a structural and an intrinsic effect. When all available sectors are examined, we see the picture shown in Figure 5.2, where the intrinsic effect is fairly volatile and strongly related to movements in total private R&D intensity.

[64] The weight of each individual country is based on their share within total value added.

Figure 5.2 Breakdown of the Dutch shortfall in private R&D intensity (vis-à-vis the OECD average), 1987-2001



Source: calculations by the Dutch Ministry of Economic Affairs based on the OECD ANBERD and STAN databases.

The sector composition effect, on the contrary, is fairly stable, showing a slight downward trend over time. In 2001 the sector composition effect was responsible for 61% of the total R&D shortfall in the Netherlands compared with the OECD average.[65] The extent of the sector composition effect depends partly on the sector aggregation used in the analysis. If we use only the five main industries, we get quite different results. In this case, the sector composition effect is responsible for only 25% of the Dutch private R&D shortfall compared with the OECD average. However, this level of aggregation ignores differences between countries within the manufacturing sector. Given that these differences can be quite substantial, a disaggregation of total manufacturing is preferred.[66]

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65 This calculation shows a total private R&D gap of 0.60 percentage points between the Netherlands and the OECD average. This differs from the private R&D gap of 0.54 percentage points mentioned in Section 5.1. The difference is due to the calculation of value added. In the industry-level calculations, gross value added is expressed at *basic prices*; whereas in the macro figures – in Section 5.1 – GDP at *market prices* is used as the denominator for the private R&D intensity. Since the sector composition effect explains 61% of the total private R&D gap, it contributes 0.33% points to the private R&D gap based on GDP at market prices (61% of 0.54).

66 Of course, one can ask whether more sub sectors should be distinguished within the total services sector. We also conducted a sector composition analysis for the period 1994-2001, which discriminates between sub sector within the total services sectors. The results of this alternative sector composition analysis differ only marginally from our main sector composition analysis, because of the predominantly low level of private R&D intensity in the services sector.

5.2.3 *Endogenising the sector composition effect*

In the previous section we showed that the sector composition effect has a fairly strong influence (i.e. 61%) on the total R&D shortfall in the Netherlands compared with the OECD average. This raises the question which underlying factors determine the knowledge-extensive sector composition of the Netherlands. The discussion is dominated by two different points of view. On the one hand, the sector composition of a country could be regarded as exogenous; one might think, for example, of constant geographic features, climatic circumstances, a fixed institutional framework and cultural background. The decisive factor in this case is path-dependency and a radical change in the sector landscape is difficult to realise.[67] On the other hand, one could regard the sector composition as an endogenous variable, which implies that the technological competitiveness of a country is reflected in its economic structure. A positive sector composition effect is not, or at least not solely, the consequence of more or less coincidental circumstances, but the result of successful competition on technology markets. This implies that a favourable sector composition is by no means an unwavering possession, nor is a negative sector composition effect necessarily permanent.

In this study we shall consider the possibility of an endogenous sector composition. Practical examples provide some ground for the view of an endogenous industry structure. Indeed, in the past ten years remarkable changes have occurred in several countries. Finland is the most striking example: the sector position effect changed from a negative 0.5 percentage points to a positive 0.8 percentage points, an increase of 1.3 percentage points. Canada is a less extreme case, but still shows an increase of 0.4 percentage points.[68] These examples illustrate that the sector composition may perhaps not be regarded as a constant factor. It is unlikely that such strong transformations occur by coincidence.

The next step is to examine the factors that affect the sector composition of a country. Our model uses three variables. The first two are the intrinsic component of private R&D expenditure and total public R&D expenditure. An increase in R&D expenditure improves the sector composition effect. The underlying idea is that R&D investments yield a higher technological output which, in turn, secures or strengthens the market position of companies. This allows the share of technological industries to increase within an economy and consequently boosts the sector composition effect. The third variable in the econometric analysis is an indicator for price competitiveness. This indicator is constructed by calculating the relative unit labour costs compared with those of the competitors in manufacturing industries. Intuitively, an increase in relative unit labour costs adversely affects the sector composition effect, because higher relative labour costs undermine the competitive position on the international market. In turn, this reduces value added of manufacturing industries vis-à-vis other countries, which has a negative impact on the sector composition effect.

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[67] See David (1985) for the importance of path-dependency and the effects of historical 'lock in'.

[68] These are percentage points of a country's total value added.

The following fixed effects model was estimated using OLS:

$$STR_{i,t} = \alpha + \beta(STR_{i,t-1} - \alpha - \sum_i f_i DUM_i - \phi(LAB_{i,t-2})) + \gamma(INT_{i,t-1} + PUB_{i,t-1}) + \phi(LAB_{i,t-1}) + \sum_i f_i DUM_i + \varepsilon_{i,t} \tag{5.2}$$

In equation (5.2), *STR* represents the sector composition effect as a percentage of total value added, *LAB* symbolises the relative unit labour costs vis-à-vis competitors in other OECD countries (expressed as a percentage deviation from 1995)[69], *INT* represents the intrinsic effect as a percentage of total value added (private R&D intensity adjusted for the sector composition effect), *PUB* denotes the difference in public R&D intensity between the Netherlands and the OECD average[70] and *DUM* are country dummies. The indicia *i* and *t* refer to respectively countries and years. The three explanatory variables – *INT, PUB* and *LAB* – are included with a lag of one year. This means that a shift in private or public R&D intensity or a change in the relative unit labour costs affects the sector composition effect with a one year lag.

Besides these three explanatory variables, a lagged dependent variable is included in the equation, because the effect of shifts in the R&D variables can spread out over many years.[71] In the model we choose to apply a decreasing geometric progression solely on the two R&D variables (i.e. *INT* and *PUB*).[72] This method relates to the concept of R&D capital. The stock of R&D capital is calculated by accumulating R&D expenditure over time and taking into account the depreciation of the existing R&D capital stock. Thus, R&D expenditures are regarded as investments which generate revenues over a long period of time. This argument does not apply to the relative unit labour costs, hence we do not relate the Koyck transformation to this variable. Last of all, country dummies have been included in the equation to take consideration of country-specific fixed effects. The estimation results are shown in Table 5.1.

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69 The relative unit labour costs relate to manufacturing industries. The data are taken from OECD Economic Outlook database.

70 Public R&D intensity is defined as public R&D expenditure (i.e. R&D expenditure of higher education institutions and public research institutes) as a percentage of total value added. The data are from OECD Main Science and Technology Indicators, 2004-2.

71 In the econometric literature a lagged dependent variable is also referred to as a *Koyck lag* or *Koyck transformation* (see e.g. Seddighi *et al.*, 2000, pp. 132 ff; Wooldridge, 2003, p. 300). The main idea behind this method is the introduction of an infinitely decreasing geometric progression: the effect of a mutation in one of the independent variables on the dependent variable is only fully realised after an infinite number of periods. In other words, the Koyck lag implies a geometrically declining effect of past events on the current situation. The speed of this transformation depends on the size of the Koyck coefficient (coefficient β in equation (5.2)): the higher coefficient β (the closer to 1), the longer the transformation will take place.

72 A potential risk of using a lagged dependent variable in OLS is that the lagged dependent is correlated with the error terms, causing potential bias (see McKinnish, 2005; Verbeek, 2004, p. 362). However, we prefer our model to be estimated in levels, because taking first differences implies that we lose information of the long-run relationship between the levels of variables (see Greene, 2000, p. 790). We conduct alternative estimations using an error correction model in Annex 2 to examine if our OLS results are biased. The robustness analysis shows that potential bias is marginal at best.

Table 5.1 Endogenising the sector composition effect[73]

	Coefficient	Std. error	t-value	P-value
α	-0.449	0.102	-4.41	0.00
β	0.864	0.061	14.04	0.00
γ	0.159	0.051	3.10	0.00
ϕ	-0.002	0.001	-3.31	0.00
R^2	0.98	Durbin-Watson	1.86	
Adjusted R^2	0.97	Durbin's h-statistic	9.73	
Number of observations	209			

Commentary: Estimations were conducted using *White Heteroskedasticity-Consistent Standard Errors & Covariance* to adjust for possible heteroskedasticity in the residuals.

All the explanatory variables have a significant impact on the sector composition effect. The *constant* term is equal to -0.449. This effect can be regarded as the *exogenous component* of the Dutch sector composition effect, which represents the sector composition effect in a situation where the Netherlands has an intrinsic effect of zero, a public R&D intensity equal to the OECD average and relative unit labour costs at the same level as in 1995 (the reference year of this variable). It can be interpreted as the Dutch comparative disadvantage in R&D (see footnote 62). The direct effect of a change in private R&D equals 0.159. This means that an increase of 1 percentage point of the *intrinsic effect* (as a percentage of the total value added) results in an increase of the sector composition effect of 0.16 percentage points one year later. The same applies to *public R&D*.[74] The *lagged dependent variable* has a coefficient of 0.864, meaning that a boost of the intrinsic effect or public R&D intensity has a continuous effect over a long period of time. The long-term effect of a change of the intrinsic effect and the public R&D variable is equal to:

$$\psi = \gamma(1+\beta+\beta^2+\beta^3+...) = \gamma\left(\frac{1}{1-\beta}\right) = 0.159\left(\frac{1}{1-0.864}\right) = 1.16 \tag{5.3}$$

The coefficient for the *relative unit labour costs* is -0.002, which can be interpreted as follows. Suppose that the index of the relative unit labour costs increases by ten points, which implies that, in comparison with other countries, the Netherlands becomes ten percent more expensive than was the case in 1995, the reference year. After one year, this results in a decrease of the

73 Country dummies are not shown in the Table 5.1.

74 The effect of public R&D on the sector composition effect is equated with the effect of private R&D. If the effects of the two variables are estimated separately, the coefficient of private R&D is 0.14 (t-value = 3.98), the coefficient of public R&D amounts to 0.27 (t-value = 3.16) and the Koyck coefficient equals 0.84 (t-value = 19.24). Given the implausible (high) effect of public R&D, a test was conducted to check if the effect of public R&D differs significantly from the effect of private R&D. The results of this test show that the estimated coefficients do not differ significantly from each other. As a consequence, the effects of both public and private R&D are estimated simultaneously using *one* coefficient (see γ in equation (5.2)).

sector composition effect of 0.02 percentage points. As explained above, a change in unit labour costs has no lasting effect in the years afterwards.

A problem with the inclusion of a lagged dependent variable is that the Durbin-Watson statistic is biased towards 2, making it less reliable (Green, 2000, pp.542; Seddighi *et al*., 2000, pp. 154). In order to test if autocorrelation occurs in our specification, Durbin's *h*-statistic can be constructed:

$$h = r\sqrt{\frac{N}{1 - N(s_b)^2}} \tag{5.4}$$

where r is the correlation coefficient for the first order lag of residuals (0.31), N is the number of observations (209) and s_b represents the standard error of the lagged dependent variable (0.06). We test for our nil hypothesis that autocorrelation exists in the first lag of the residuals. We reject our nil hypothesis if $h < -1.97$ or >1.97. Table 5.1 shows that our calculated Durbin's h-statistic satisfies the rejection of the nil hypothesis. In addition, we conducted a Breusch-Godfrey Serial Correlation LM Test (see Wooldridge, 2004, p. 401 ff), which confirms that serial correlation of multiple order does not occur.

5.2.4 The Netherlands in 2035

The results from the previous sub section enable the simulation of different scenarios for the future R&D position of the Netherlands compared with the OECD. Figure 5.3 demonstrates a simulation of the corporate R&D intensity if the circumstances of 2001 remain unchanged. Hence, the intrinsic effect, the public R&D intensity, and the relative unit labour costs vis-à-vis the OECD are fixed at the same level as they were in 2001. The simulation presented in Figure 5.3 illustrates that, under fixed circumstances, the negative development of the sector composition effect and the total private R&D shortfall of the Netherlands will continue to decrease in the future.

Figure 5.4 shows the effect of a stimulus in private R&D expenditure. An improvement in the intrinsic effect would raise the sector composition effect. Taking the objectives of the Lisbon Agenda into consideration – Europe aims to become the most dynamic and competitive knowledge-based economy in the world and the Netherlands thrives for a leading position within the EU by 2010 – a simulation is conducted in which the negative Dutch intrinsic effect gradually diminishes over time compared with the OECD average. In other words, the intrinsic R&D shortfall of the Netherlands is eliminated proportionately over time. In addition, the development of the sector composition effect from the *ceteris paribus* simulation plotted in Figure 5.3 has been included in Figure 5.4. This way, the difference in the development of the sector composition effect *with* and *without* a stimulus of the intrinsic effect becomes visible in Figure 5.4.

Figure 5.3 Simulation of the development of the sector composition effect and the total private R&D gap if circumstances do not change after 2001

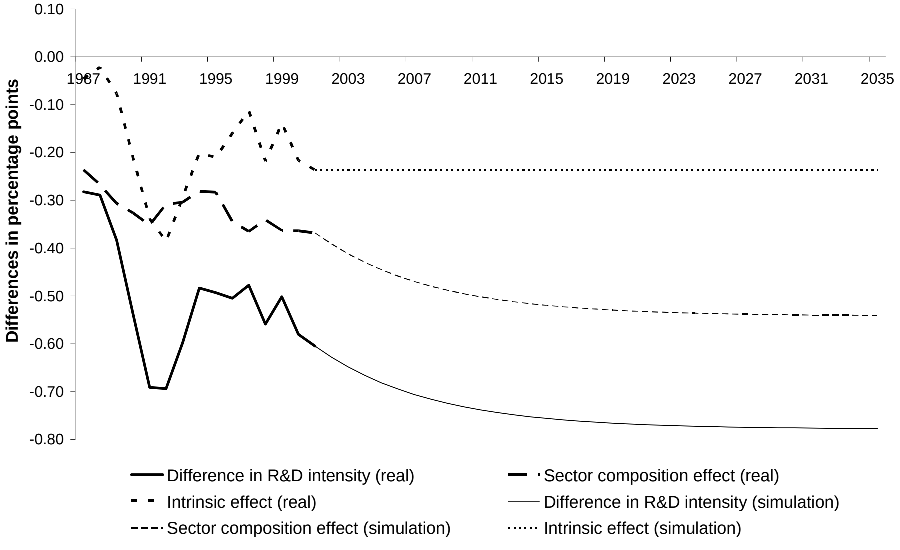


Figure 5.4 Simulation of the development of the sector composition effect and the total effect as a result of an improvement in the intrinsic effect

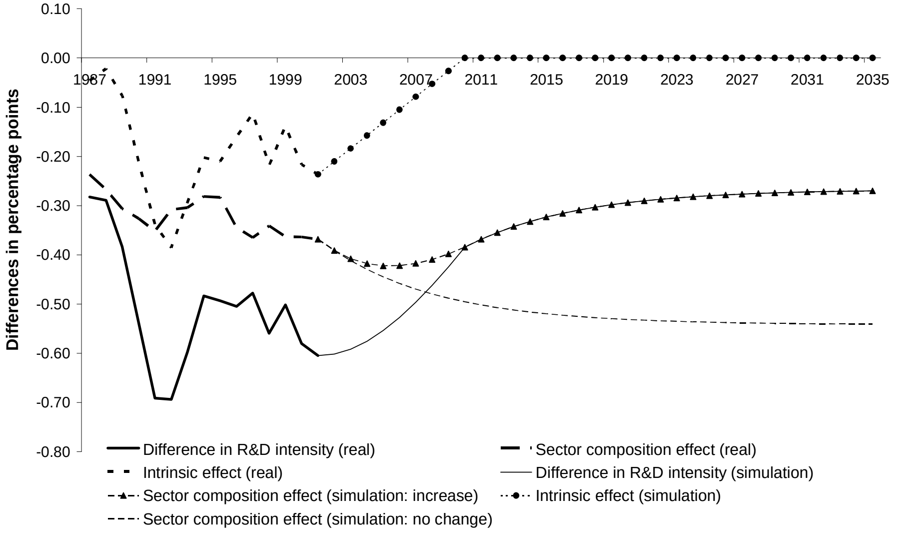


Figure 5.4 shows several interesting aspects. First of all, the sector composition effect shows a downward trend (simulation: increase) in the first few years after the intrinsic boost – up to 2006. It seems that an increase in private R&D expenditure does not immediately result in an improvement of the sector composition. The deterioration of the intrinsic effect from the previous years is still dominant. To a certain extent, the sector composition effect reflects past R&D expenditure. Therefore, it takes a few years for an improvement of the intrinsic effect to filter through to the sector composition effect.

Secondly, the effect of an intrinsic improvement on the sector composition effect carries on over a long period of time, even after the impetus itself has died out. After 2010, the upward development of the sector composition effect continues over time. Just as the negative results from the past can have a long-lasting effect on the present situation, a positive advancement of current R&D expenditure has a long-lasting effect on the future development of the knowledge-intensity of the economy (i.e. the sector composition effect). This is the result of the Koyck transformation in our model.

Last of all, the impact of an elimination of the negative intrinsic effect in 2010 on the development of the sector composition effect up to 2035 is considerable. If circumstances remain unchanged after 2001, the sector composition effect (simulation: no change) slips to a shortfall of 0.45 percentage points compared with the OECD average. Reducing the negative Dutch intrinsic effect to zero (in 2010) causes the sector composition effect (simulation: increase) to narrow down the deficit to 0.27 percentage points. If there are no additional R&D investments from 2001 onwards, we see a decline in the sector composition effect which is, in the long term, *twice as high* as in the situation where the intrinsic effect is brought to zero. The difference between the two simulated sector composition effects – 0.27 percentage points – corresponds with the lagged effect of private R&D expenditure. A long-term effect of 1.16 was calculated in Section 5.2.3. This figure, when multiplied by the intrinsic increase of 0.23 percentage points, results in the 0.27 percentage points mentioned here.

5.3 INTERNATIONALISATION OF R&D

So far, we have looked at the sector composition effect, which explains the larger part of the Dutch R&D shortfall vis-à-vis the OECD. In the remainder of this chapter, the negative intrinsic effect of the Netherlands will be analysed by looking at several determinants of private R&D, the internationalisation of R&D being the first. To examine the effect of the internationalisation of R&D on private R&D expenditure in the Netherlands, two types of investment need to be considered: outward R&D investments and inward R&D investments. Outward R&D investments are R&D investments by domestic businesses abroad.[75] Inward R&D investments

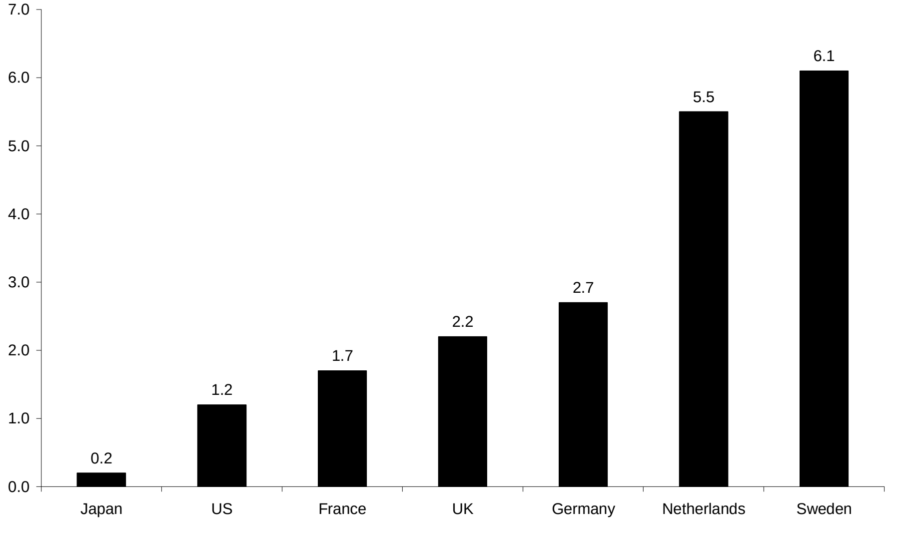
[75] Definition from OECD (2004, p. 11): *"For outward investment, in principle, the ultimate host country should be considered, but if it is difficult to identify it, the concept of "immediate host country" can be used."*

are R&D investments by foreign affiliates operating in the domestic country.[76] The influence of R&D internationalisation on private R&D expenditure vis-à-vis foreign countries is ultimately determined by the net balance between the outward R&D investments (which relates to the *relocation of R&D*) and the inward R&D investments.

5.3.1 Outward R&D: relocation of R&D

Firms can invest in R&D abroad. These outward R&D investments can put pressure on the R&D intensity in a country, if these investments are at the expense of R&D at the home base.

Figure 5.5 Outward R&D investments as a percentage of value added, total manufacturing, 2001



Source: calculations by the Dutch Ministry of Economic Affairs based on the AFA database, the STAN database and the Main Science and Technology Indicators 2005-1, all from the OECD. Outward R&D from Sweden, the US and Germany emcompass total outward R&D investments. Outward investments from France, Japan, the Netherlands and the UK to twelve other countries: Canada, Finland, France, Japan, the Netherlands, Poland, Portugal, Spain, Sweden Turkey, the UK and the US.

Figures on total outward R&D investments are scarce and not available for the Netherlands. Based on the OECD Activities of Foreign Affiliates (AFA) database we nevertheless can get an

[76] Definition from OECD (2004, p. 11): *"For inward investment, the geographical origin of the foreign affiliate corresponds to the home country of the parent company. In principle, the ultimate beneficial owner (UBO) should be considered, but given that some investments are carried out through holding companies or affiliates different from that in which the parent company is located, it is difficult to identify the initial investor. In this case, the country of origin is that of the 'immediate controller'."*

indication of the amount of outward R&D from the Netherlands (see Figure 5.5). The figures should be treated with some caution. The outward R&D investments are based on inward R&D figures in other countries. As only a limited number of countries could be included in the calculations, the figures represent only a part of the total outward R&D investments.

Figure 5.5 shows that, compared with the other countries in the sample, the Netherlands experiences relatively high outward R&D investments as a ratio of value added in 2001. The smaller countries in particular (the Netherlands and Sweden) cope with a considerably higher outflow of R&D than the large countries (the US and Japan). Multinationals in small countries inevitably have to obtain complementary knowledge from elsewhere in the world, unlike multinationals in large countries. This is a consequence of country size and – closely interrelated – the openness of the economy. When assessing figures on outward and inward R&D investments, a correction should be made for the openness/size of the economy (see Section 5.3.2 for argumentation). The Netherlands holds an average position in outward R&D investments if such an adjustment is made.

The high outward R&D investments in the Netherlands as shown in Figure 5.5 (without a correction for openness of the economy) only put pressure on the R&D intensity if they are at the expense of R&D at the home base. In Chapter 4 and 8 of this thesis, however, it is shown that R&D has not been relocated on a large scale from the Netherlands to other countries. The high level of outward R&D investments in the Netherlands (which are not at the expense of R&D at the home base) can also be considered a positive trend, as it demonstrates that the Dutch knowledge-intensive multinationals are well-connected to the international knowledge networks that are important to them.[77]

5.3.2 Inward R&D: foreign R&D investments

The OECD AFA database can be used to determine the Dutch position on the inflow of R&D. Data are available for Canada, the Czech Republic, Germany, Finland, France, Ireland, Japan, the Netherlands, Poland, Portugal, Spain, Sweden, the UK and the US, which together account for almost 90% of total private R&D conducted within the OECD. Hence, the subset of countries for which data are available on inward R&D investments is sufficiently representative to serve as an indicator for the OECD average.

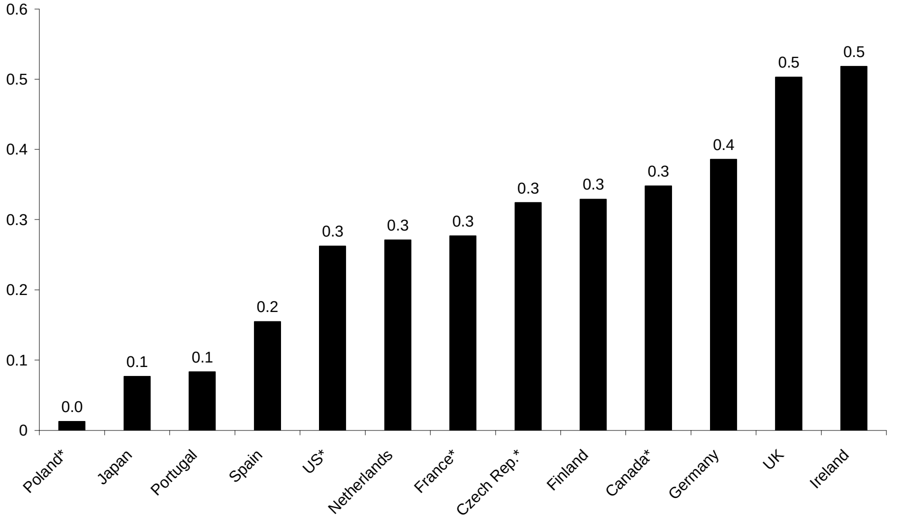
The inward R&D investments as a percentage of GDP of the total business sector – in 2001– is illustrated in Figure 5.6.[78] The figure shows that the Dutch position on inward R&D investments as a percentage of GDP does not deviate substantially from the international average. However,

[77] According to economic theory, international R&D activities of multinationals are based on market considerations or the desire to gain access to state-of-the-art knowledge and expertise, which is available in complementary fields of technology (see Chapters 4 and 7 of this thesis).

[78] In more recent years the international position on inward and outward R&D has remained roughly the same (see Chapter 4 and 8 of this thesis). We are, however, interested in the Dutch position in 2001, as this is the year of reference of our analysis.

as mentioned in the previous section, openness of the economy should also be taken into account when considering the internationalisation of R&D.

Figure 5.6 R&D investments by foreign affiliates as a percentage of GDP, FDI concerns total business sector, 2001 (* = 2002)



Source: calculations by the Dutch Ministry of Economic Affairs, based on the AFA database and the OECD Economic Outlook database.

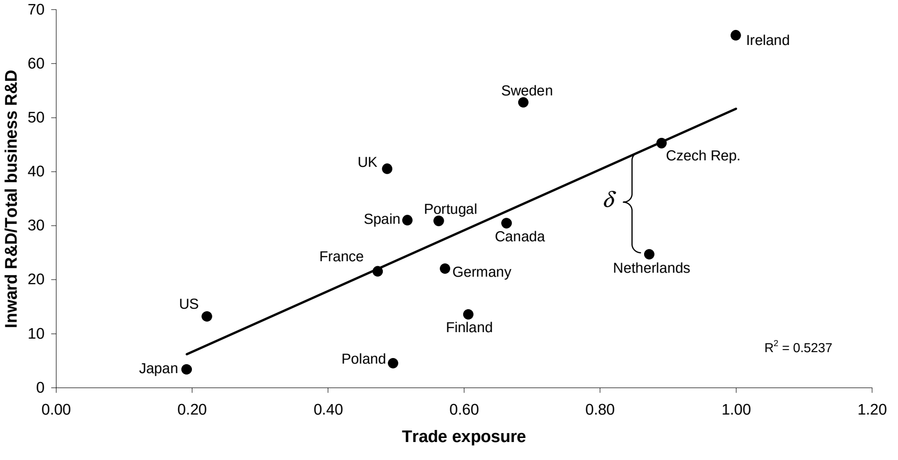
Adjusting for openness of the economy

To determine the contribution of inward R&D investments to the R&D shortfall in the Netherlands, the data from Figure 5.6 must be adjusted for openness of the economy. We hypothesize that inward R&D investments are more important in small, open economies than in large, closed economies. It is commonly believed that openness to global trade is more important for small economies than for large ones and subsequent empirical research has confirmed that small economies are indeed more open (see Alesina and Wacziarg, 1998; Ades and Glaesser, 1999). Open economies are more tuned in to the global market for goods and production factors than closed economies. Hence, one would expect that the share of foreign R&D in total R&D investments is higher in (small) open economies than in (large) closed economies.

Figure 5.7 lends credence to our hypothesis by showing a positive correlation between inward R&D investments in relation to total business R&D (*y*-axis) and openness of the economy (*x*-axis). Openness of the economy is represented by an indicator for *trade exposure*, drawn from

Bassanini *et al.* (2001, p. 25). This indicator represents the sum of the export intensity and the degree of import penetration.[79] The export intensity is defined as the total exports in relation to GDP. The import penetration is calculated by placing the total imports in relation to domestic sales (= gross domestic product + total imports – total exports) and multiplying this by: 1 minus the export intensity (expressed as a perunage). It seems that in 2001 the Netherlands – given the openness of the economy – attracted relatively little foreign R&D investment compared to the international average. This is represented by δ in Figure 5.7.

Figure 5.7 Correlation between inward R&D investments and openness of the economy, total business sector, 2001



Source: Calculations by the Dutch Ministry of Economic Affairs based on the AFA database and Main Science and Technology Indicators 2004-2 and OECD Economic Outlook database.

Econometric analysis

To formalise and confirm the relationship between inward investments and openness of the economy, we conducted an econometric analysis using international panel data. Inward R&D expenditure in relation to total business R&D (Figure 5.7) is not, however, a suitable dependent variable for our analysis. First of all, total business R&D (denominator) is dependent on inward R&D as well. Secondly, we need a dependent variable in which only the *additional effect* of foreign R&D investments is expressed. After all, we want to adjust for all kinds of factors which affect inward R&D investments, such as the sector composition effect and the investment climate in general. To obviate the above-mentioned problems, we constructed a dependent variable which is expressed as the ratio of inward R&D in relation to domestic R&D, the latter

[79] A more conventional indicator for openness of the economy is the sum of exports and imports as a ratio of GDP. However, this indicator does not filter out the import component within total exports.

representing total business R&D minus inward private R&D. If one assumes that both foreign and domestic R&D are affected equally by factors which determine the investment climate (human capital, the quality of the knowledge infrastructure, etc.), one can adjust for the effect of these factors by using this ratio.

$$INW_{i,t} = \alpha + \beta TRADE_{i,t} + \phi TREND_t + \gamma DUM_t^{Ire} + \xi DUM_{1999,2000}^{Swe} + \varepsilon_{i,t} \qquad (5.5)$$

for
i = country; t = year

$(i,t) \in$ (Canada, 1990-2001), (Czech Republic, 1997-2001), (Finland, 1995-2001), (France, 1994-2001), (Germany, 1993-2000), (Hungary, 1992-1998), (Ireland, 1991-1999), (Japan, 1991-2000), (the Netherlands, 1995-2000), (Poland, 1997-2001), (Portugal, 1999-2001), (Spain, 1991-2001), (Sweden, 1991-2000), (United Kingdom, 1994-1999), (United States, 1991-2001)

The estimated model is presented in equation (5.5), in which *INW*[80] stands for the inward R&D investments in relation to domestic R&D expenditure and *TRADE* represents the trade exposure variable from Bassanini *et al.* (2001), which represents – as already mentioned – the openness of the economy.[81] Furthermore, a trend variable (*TREND*) and two dummy variables for Ireland (DUM^{Ire}) and Sweden (DUM^{Swe}) are included in the equation. A dummy for Ireland is used, because Ireland shows extreme values over the entire period of observation. This leads to a substantial positive bias of the estimation results. Sweden shows a break in series from 1999 onwards, so a dummy variable, which relates only to 1999 and 2000, is included to obviate any bias. Country dummies were not included in the equation as this would eliminate the cross-section dimension. After all, we are particularly interested to what extent the openness of the economy explains differences in the *level* of foreign R&D investments between countries.

The results of the econometric analysis are presented in Table 5.2.[82] The effect of the trend variable is insignificant and has therefore been removed from the equation. The estimated effect probably does not differ significantly from zero because the openness variable has a trend-related development over time. This dispenses the need to include a separate trend variable in the specification. The openness variable (coefficient β) has a significant effect on inward R&D investments in relation to domestic R&D. An R^2 of 0.65 is found, which implies that openness of the economy (in combination with the two dummies for Ireland and Sweden) explains 65% of the variance in the data of the dependent variable. The low Durbin-Watson statistic is due to

80 Data derived from the OECD Activities of Foreign Affiliates (AFA) database and OECD Main Science and Technology Indicators, 2004-2.
81 Data from the OECD Economic Outlook database were used for both the *OPENNESS* and the *TRADE* indicator.
82 We conducted several robustness checks, where we experimented with weighted estimations and natural logs. The results from these estimations do not deviate much from the ones presented in Table 5.2 and are available on request.

the omission of country dummies. As a result, unexplained differences in levels between countries are expressed in serially correlated residuals.

Table 5.2 Estimation results from the econometric analysis

	Coefficient	Std. error	t-value	P-value
α	-0.060	0.121	-0.50	0.62
β	0.788	0.309	2.55	0.01
γ	1.264	0.193	6.56	0.00
ξ	0.414	0.091	4.55	0.00
R^2	0.65	Durbin-Watson	0.42	
Adjusted R^2	0.64			
Number of observations	129			

Commentary: Estimations were conducted using *White Heteroskedasticity-Consistent Standard Errors & Covariance* to adjust for possible heteroskedasticity in the residuals.

Contribution of inward R&D investments to the Dutch R&D shortfall

The results from the econometric analysis can be used to quantify the contribution of inward R&D investments to the Dutch shortfall in private R&D in 2001. The first step is to determine how much foreign R&D investments the Netherlands needs to attract in order to reflect its openness of the economy (this is illustrated by δ in Figure 5.7). Using the openness of the economy observed in 2001, the Netherlands should have a ratio of inward R&D to domestic R&D of 63%, as opposed to the actual value in 2001 of 32%.[83] In other words, given the openness of the Dutch economy, the Netherlands should attract an additional 31 percentage points more foreign investments in relation to domestic R&D (63%-32%).

The foreign R&D intensity in the Netherlands in 2001 amounts to 0.27% (=100×(inward R&D/GDP)). An increase of the inward R&D investments in relation to domestic R&D from 32% to 63% raises foreign R&D intensity to 0.52% (=(0.63/0.32)×0.27).[84] Consequently, in 2001 the shortfall in inward R&D investments – taking into account the openness of the Dutch economy – has had a negative effect of 0.25 percentage points (0.52%-0.27%) on private R&D intensity of the Netherlands compared with the OECD average.

The exercise above shows the effect of inward R&D investments (in relation to domestic R&D) in the Netherlands for 2001. Over the period 1995-2001, the negative effect of foreign R&D investments on the Dutch private R&D shortfall dropped from 0.36 percentage points in 1995 to 0.25 percentage points in 2001. This was caused by a steep increase in inward R&D investments

[83] The observed openness of the Dutch economy in 2001 is 0.87. Using the results presented in Table 5.2, a fitted value of 0.63 can be obtained.

[84] This percentage indicates that, given the open character of the Dutch economy, we may expect that approximately half of the total Dutch private R&D expenditure would be conducted by foreign businesses.

in the Netherlands in proportion to domestic R&D expenditure, which rose from 0.15 in 1995 to 0.29 in 2000 (second row in Table 5.3).[85]

Table 5.3 Contribution of inward R&D investments to the difference in R&D intensity between the Netherlands and the OECD (NL-OECD)

	1995	1996	1997	1998	1999	2000	2001
Contribution to R&D shortfall	0.36	0.32	0.31	0.27	0.29	0.23	0.25
Ratio inward/domestic R&D in NL	0.15	0.19	0.23	0.22	0.25	0.29	0.27

5.4 OPENNESS OF THE ECONOMY

The previous section addressed the importance of openness of the economy when assessing the effect of R&D internationalisation on private R&D expenditure. Openness of the economy has a separate effect on the level of private R&D expenditure as well (see Helpman, 2004; Falk, 2006). There are two explanations for this. First of all, businesses that operate in a more open economy are exposed to international competition to a larger extent than businesses in closed economies. Given the importance of innovation in international competition, it is reasonable to expect that more openness leads to more private R&D expenditure. For instance, Smulders and Klundert (1995) show that import competition encourages investment in R&D by simultaneously reducing mark-ups and increasing the level of domestic concentration. Secondly, a higher level op openness to foreign trade opens up possibilities to operate on larger export markets and exploit the results of R&D and innovation on a larger scale. Pires (2006) provides evidence that firms located in countries with more demand (i.e. a larger market) become more competitive because they have strong incentives to perform R&D.

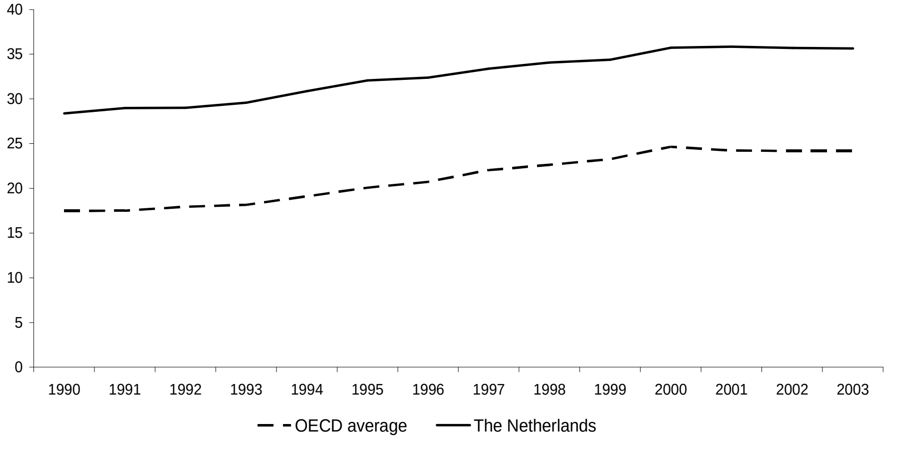
There are only a few empirical studies on the effect of openness of the economy on private R&D. Bebczuk (2002) finds a negative effect in an estimate for 88 countries. According to the author, this counter-intuitive result can be attributed to the role of international trade in preventing the duplication of R&D activities. Though this implies a more efficient allocation of research funds across the countries worldwide, it could discourage some countries from engaging in R&D in the first place. However, most studies find that openness of the economy has a positive effect on private R&D intensity. Reinthaler and Wolff (2002, 2004), Falk (2004), the European Commission (2003) and Donselaar and Segers (2006) all confirm the mainstream results in the literature and find a positive relationship between openness of the economy and private R&D expenditure. For our own calculation, we prefer to use the elasticity of 0.24 from Donselaar and Segers (2006). There are two reasons for this. First of all, the effect of openness of the economy in this study is estimated in combination with many other variables; thus

[85] The ratio inward R&D in relation to domestic R&D did not increase because of a reduction of domestic R&D expenditure.

limiting the risk of omitted variable bias (see e.g. Wooldridge, 2003, pp. 89 ff; Verbeek, 2004, pp. 55 ff). Secondly, the openness variable used by Donselaar and Segers (2006) encompasses the indicator *trade exposure* from Bassanini *et al*. (2001), but the data has been adjusted for the size of economies (see Annex 3 of Chapter 9 of this thesis for more information). Adjusting for size is important, as smaller countries are generally more open than larger countries because they have a smaller share in the global economy.

International position and contribution to Dutch R&D shortfall
In Figure 5.8 the corrected openness variable is compared with the OECD average. This figure shows a consistently higher level of openness in the Netherlands over the period 1990-2003.

Figure 5.8 Openness of the economy adjusted for the size, 1990-2003



Source: OECD Economic Outlook database. The OECD average was calculated based on a representative sample of twenty OECD countries.

The development of the openness of the economy in the Netherlands and the OECD was virtually identical in this period. The question is how the relatively large level of openness in the Dutch economy contributes to its private R&D intensity vis-à-vis the OECD average in 2001. Because the effect of openness on private R&D expenditure is estimated using a logarithmic specification, the coefficient has to be transformed in order to calculate the contribution of the openness variable to the Dutch shortfall in corporate R&D. Box 5.1 illustrates this calculation. Based on the calculation in Box 5.1, we can conclude that – in 2001 – the more open economy of the Netherlands compared to the OECD generates a positive effect of 0.10 percentage points on the Dutch intrinsic effect. Or in other words, the relatively open Dutch economy reduces the Dutch R&D shortfall vis-à-vis the OECD average.

Box 5.1 Contribution of opennes of the economy

In 2001, the adjusted openness variable in the Netherlands amounts to 35.8. The weighted OECD average in that year is 24.2. The ratio (35.8/24.2) combined with Donselaar and Segers' (2006) elasticity of 0.24 results in a positive effect of 9.9% on Dutch R&D intensity in 2001 compared with the OECD average ($100\times((35.8/24.2)^{0.24}-1) = 9.9$).[86] This percentage can be used to compute a 'hypothetical R&D intensity' for the Netherlands in 2001, which represents the situation where the openness of the Dutch economy is similar to the openness of the OECD. The calculation is as follows: 1.10% (actual R&D intensity in 2001) × 1/(1+9.9/100) = 1.00% of GDP. The actual situation in 2001 minus the hypothetical situation reveals the positive contribution of the openness of the Dutch economy on the R&D shortfall in 2001, which amounts to 0.10 percentage points (= 1.10% minus 1.00%).

To conclude this section, Table 5.4 shows the contribution of the openness variable over time. The positive contribution dropped slightly from 0.12 percentage points in 1990 to 0.10 percentage points in 2001.

Table 5.4 Contribution of openness of the economy to the difference in private R&D intensity (NL-OECD)

	1990	1995	1998	2000	2001	2002
Contribution	0.12	0.11	0.10	0.09	0.10	0.09

5.5 OTHER DETERMINANTS OF PRIVATE R&D

In the previous sections we examined the three determinants of private R&D that contribute most heavily to the private R&D shortfall of the Netherlands in 2001 compared with the OECD average. Private R&D is, of course, also influenced by many other factors, e.g. economic regulations, government funding of R&D, the IPR regime, the impact of financial factors and fast-growing firms. It is beyond the scope of this chapter to extensively examine the impact of all these factors and, besides, these determinants do not contribute substantially to the private R&D gap of the Netherlands in 2001. We refer to Erken and Ruiter (2005) for a more thorough examination of these determinants. In this section we limit ourselves to a general overview of the data in combination with the elasticities from the empirical literature and a description of the methodology used to determine the contribution of each individual driver of private R&D. Based on this information, the partial contributions calculated in the decomposition table in Section 5.6 can be reproduced.

86 This calculation is conducted by transforming the estimated logarithmic specification into a multiplicative specification, in which the estimated elasticities reflect the exponents of the original logarithmic variables on the right-hand side of the equation.

Table 5.5 Methodology used to calculate partial effects

1		**Competition/ economic regulation**	**Real interest rate**	**Public R&D**	**Intellectual property rights (IPR)**	**Capital income share**	**Government funding of private R&D**	**Fast-growing firms**
2	***Theoretical and empirical literature***	Aghion and Howitt (1998); Aghion *et al*. (2005); Aghion *et al*., (2001), Blundell *et al*. (1999); **Bassanini and Ernst (2007)**	Becker and Pain (2008); Lederman and Maloney (2003); **Guellec and Ioannidis (1997)**	European Commission (2004); Reinthaler and Wolff (2004); Falk (2006); **Donselaar and Segers (2006)**	Aghion *et al*., (2001); Blundell *et al.* (1999); **Donselaar and Segers (2006)**; Lederman and Maloney (2003); Varsakelis (2001)	Symeonidis (1996) and Hall (2002); Himmelberg and Petersen (1994); **Donselaar and Segers (2006)**	Guellec and van Pottelsberghe (2003); **Hall and Van Reenen (2000); Lichtenberg (1984, 1987); Scott (1984); Bloom *et al.* (2002)**	Ehrhardt *et al*. (2004); **Baljé and Waasdorp (1999)**
3	***Definition of independent variable***	Index on inward-oriented economic regulation, ranging from 0 to 6	Long-term interest rate minus GDP deflator at market prices	R&D expenditure by higher education institutes (HERD) and public research institutions (GOVERD)	Index covering various elements of the IPR regime, ranging from 0 to 5	Gross capital income of firms as a % of value added of firms	R&D tax incentives, R&D subsidies/credits and R&D orders by the government	Share of firms that experienced a rise in turnover of 60% over the last three years [**]
4	***Data sources***	Nicoletti *et al.* (1999); Conway (2005)	OECD Economic Outlook database	OECD Main Science and Technology Indicators (MSTI)	Ginarte and Park (1997); Park and Wagh (2002)	OECD Economic Outlook database	Beta index from Warda (1996, 2001); OECD Economic Outlook database; OECD MSTI	International Benchmark Entrepreneurship[***]
5	***Effect***	Semi-elasticity: ranging between −0.274 and −0.349[*]	Semi-elasticity: −0.03	Semi-elasticity HERD: 0.20; Semi-elasticity GOVERD: 0.47	Elasticity: 0.72	Elasticity: 0.14	Additive effect: 1.0 for total of R&D stimulation	Additive effect: Fast-growing firms spend 40% more on R&D (see Annex 1)
6	***Position NL vis-à-vis OECD***	NL: 1.5; OECD: 1.6	NL: 2.9%; OECD: 4.2%	HERD NL: 0.51%; HERD OECD: 0.40%; GOVERD NL: 0.27%; GOVERD OECD: 0.23% (percentage of GDP)	NL: 4.38; OECD average: 4.53 (index ranging from 0 to 5)	NL: 37.4%; OECD: 34.3%	NL: 0.16%; OECD: 0.22% (total government funding as a percentage of GDP)	NL: 18%; OECD: 25% (percentage of all businesses with 50-1,000 employees)
7	***Year of observation***	2003	1998; the effect has a lag of three years	2001	2000; the effect of IPR on R&D has a lag of one year	2001	2001	1998-2001

Commentary: The effects presented in row 5 originate from the studies presented in **bold** in row 2. [*] For simplicity, the semi-elasticity of inward-economic regulation was fixed at −0.32. [**] An alternative definition for fast-growing firms is the so-called adjusted ‘Birch index’ used by Baljé and Waasdorp (1999, p. 51, footnote 7). [***] See Bosma and Verhoeven (2004); Peeters and Verhoeven (2005) and De Jong-‘t Hart and Verhoeven (2006, 2007).

Table 5.5 provides an overview of the studies and effects that where used to calculate the contribution of other determinants of private R&D to the Dutch gap in business R&D. First of all, we have conducted a review of the theoretical and empirical literature to get a good impression of the economic mechanisms and effects of certain determinants on private R&D expenditure. The relevant literature is shown in row 2 of the table. The next step is to ascertain the effect of a determinant based on the study or a combination of studies that prove to be most reliable from a methodological point of view. We especially focus on the comprehensiveness of the empirical models, the econometric methods used and the plausibility of the estimated effects. Most empirical studies follow a thorough methodology, which complicates the selection of studies based on the methodological criterium alone. As a consequence, in many cases we use the effects from the literature that are most moderate. The definition of the indicators, the data sources and coefficients that were used for our decomposition analysis are presented respectively in rows 3, 4 and 5 of Table 5.5.

It is important to address that in some cases it proves fairly difficult to derive output elasticities. In some cases, the outcome of studies could not directly be used for the purpose of this study. For instance, the excellent work by Blundell *et al.* (1999) and Aghion *et al*. (2001, 2005) provides valuable insights into the economic relationship between competition, IPR and innovation/R&D. However, because direct output elasticities from these studies are not easily obtained, we use the more practical study by Bassanini and Ernst (2007) for the effect economic regulation (and closely related: competition) on private R&D expenditure.

Box 5.2 Semi-elasticities

The impact of inward-oriented economic regulation on private R&D is estimated by Bassanini and Ernst (2007) using a semi-logarithmic functional form. The result can be interpreted as follows: one additional point on the index inward-oriented economic regulation (on a scale of 0 to 6) leads to a drop in private R&D intensity by 0.27 to 0.36 percentage points. For simplicity we fix the elasticity at -0.32. Unfortunately, we do not have have data for 2001, therefore use the situation in 2003 for our calculations. By linking the semi-elasticity to the relative position of the Netherlands in 2003 (vis-à-vis the OECD average) on economic regulation of -0.1 points (1.5 minus 1.6), the positive impact of economic regulation in 2003 on Dutch R&D intensity can be fixed at 3.25% (= $100 \times (e^{(-0.1 \times -0.32)} - 1)$). This percentage can be used to compute a ‘hypothetical R&D intensity’ for the Netherlands in 2001, which represents the situation where the amount of inward-oriented economic regulation in the Netherlands is equal to the OECD. The hypothetical R&D intensity is: 1.10% (actual R&D intensity of the Netherlands in 2001) × 1/(1+3.25/100) = 1.14%. The actual R&D intensity in 2001 minus the ‘hypothetical’ intensity reveals a negative contribution of the Dutch position on inward-oriented economic regulation on the R&D intensity of 0.04 percentage points (= 1.10% minus 1.14%).

To determine the contribution of a specific driver of R&D on the R&D gap of the Netherlands, the effect from the empirical literature has to be related to the position of the Netherlands on this determinant in comparison with the OECD average. This involves rows 5 and 6. The estimation methodology has to be taken into consideration as well. It is important to recognize if an empirical effect has an additive relationship with private R&D, or represents a direct output elasticity c.q. semi-elasticity. Indeed, the calculation of the contribution differs with the specification that was followed in the empirical literature. In is important to discern if studies obtain an additive effect, an output elasticity or a semi-elasticity. The method of calculation using direct output elasticities is already illustrated in Box 5.1 of Section 5.4, since the effect of openness is expressed as an output elasticity. By means of example, in Box 5.2 we illustrate how to use semi-elasticities in order to calculate the contribution to the private R&D gap.

5.6 DECOMPOSITION OF DUTCH R&D GAP

Table 5.6 provides an overview of the contributions to the Dutch R&D gap in a decomposition table (second column). Two main factors are distinguished: a *sector composition effect* and an *intrinsic effect*. In 2001 both effects were negative in the Netherlands compared to the OECD average. The determinants covered in this study jointly explain 0.48 percentage points of the private R&D shortfall in the Netherlands compared with the OECD average (the total R&D gap is 0.54 percentage points).

The sector composition effect of 0.33 percentage points explains the greater part of the R&D shortfall in the Netherlands. It is plausible that this large negative sector composition effect is not only the result of more or less constant factors. In Section 5.2 we show that the *sector composition effect* is dependent on, amongst other things, the intrinsic effect, public R&D expenditure and international price competitiveness (expressed as relative unit labour costs). Improvement in either of these variables will result in a positive change of the sector composition effect of a country, which will consequently lead to a higher private R&D intensity.

The negative (remaining) *intrinsic effect* amounts to 0.21 percentage points. In the decomposition table the contribution of the determinants of the intrinsic effect also have been quantified. Poor foreign R&D investments in the Netherlands, adjusted for openness of the economy, conveys a negative contribution of 0.25 percentage points. This large effect is, however, counterbalanced by a relatively strong positive effect of 0.10 percentage points due to the openness of the Dutch economy. The other R&D determinants only have a modest contribution (either positive or negative) to the Dutch intrinsic effect in 2001. Lower government funding (especially R&D subsidies/credits and R&D orders) in the Netherlands compared with the OECD accounts for 0.06 percentage points of the shortfall. The lower score for the Netherlands on intellectual property rights and the small number of fast-growing businesses explain respectively 0.03 percentage points and 0.02 percentage points. Positive effects emanate from the lower level of economic regulation (0.04 percentage points), higher levels of public R&D expenditure (0.04 percentage points), the higher capital income quote (0.01 percentage points) and the lower real interest rate (0.02 percentage points).

Table 5.6 Decomposition of Dutch R&D shortfall vis-à-vis the OECD average (NL-OECD), 2001, contributions in percentage points of GDP (second column), effect of 10% increase in percentages (third column)

Determinants	Contribution	Effect of 10%↑ on R&D expenditure
Sector composition effect	***-0.33%***	-
Intrinsic effect	***-0.21%***	-
Foreign R&D investments	-0.25%	2.5%
Openness of the economy	+0.10%	2.3%
Inward-oriented economic regulation	+0.04%*	-4.7%
Real interest rate	+0.02%	-1.3%
Public R&D	+0.04%	
Higher education R&D	+0.02%	1.0%
R&D of public research institutions	+0.02%	1.3%
Intellectual property rights	-0.03%	7.1%
Capital income share	+0.01%	1.3%
Government funding of private R&D	-0.06%	1.4%
Fast-growing firms	-0.02%**	0.4%
Residual	-0.06%	-
Total R&D shortfall	***-0.54%***	-

Commentary: * 2003. ** 1998-2001.

Given that the sector composition effect is largely dependent on the intrinsic effect, it is important to ascertain the adjustments that can be made to the intrinsic effect. In the third column of Table 5.6, the effect of a 10% increase of the determinants of the intrinsic effect is examined. For example, an boost of foreign investments by 10% in the Netherlands would result in a positive effect of 2.5% on the private R&D intensity. In view of the different outcomes in the empirical literature, these effects are obviously somewhat uncertain. Furthermore, one must take into consideration the magnitute of the impetus when interpreting the effects. Surely enough, a 10% increase of public R&D expenditure is easier to realise than a 10% increase of the openness of an economy or a 10% decrease of the real interest rate. In any case, the quantified effects in column three do provide an indication of the importance of each determinant for the improvement of the Dutch intrinsic position.

5.7 CLOSING COMMENTS

Since the end of the 1980s the private R&D intensity in the Netherlands has been lagging behind the OECD average. Given the importance of R&D for future economic growth, the

Netherlands clearly needs to narrow this gap. In order to do this, however, the causes of the shortfall have to be known. This study has introduced a methodology to decompose R&D differences between countries or groups of countries. Applying this methodology on the Dutch situation, it was possible to largely explain the Dutch shortfall in corporate R&D.

Table 5.7 Decomposition of R&D position of countries vis-à-vis the OECD average into a sector composition effect and an intrinsic effect, 2001

	Total R&D position	Sector composition effect	Intrinsic effect
Australia	-0.96	-0.75	-0.21
Belgium	-0.08	-0.08	0.00
Canada	-0.67	-0.04	-0.62
Czech Republic	-0.94	0.14	-1.09
Denmark	0.06	-0.35	0.40
Finland	0.91	0.79	0.12
France	-0.27	-0.06	-0.21
Germany	0.09	0.36	-0.27
Italy	-1.20	-0.26	-0.94
Japan	0.56	0.34	0.22
Korea	0.67	1.52	-0.86
Netherlands	-0.60	-0.37	-0.24
Norway	-0.86	-0.72	-0.13
Poland	-1.54	-0.45	-1.09
Spain	-1.27	-0.40	-0.87
Sweden	1.91	0.03	1.88
UK	-0.43	-0.13	-0.30
US	0.31	-0.15	0.46

Source: calculations by the Dutch Ministry of Economic Affairs based on the OECD ANBERD and STAN databases. Commentary: the total R&D position is the sum of both the sector composition effect and the intrinsic effect. Differences in the R&D intensity of a country relative to the OECD average are calculated using gross value added expressed at basic prices in the denominator, whereas conventionally R&D intensities are calculated using value added at market prices in the denominator (see footnote 65).

Analyses based on this methodology could also prove valuable to other countries in order to shed light on the causes behind their R&D position. Bearing the Barcelona objective in mind – the EU should raise total R&D expenditure to 3% of GDP – such analyses could guide individual countries in assessing their strengths and weaknesses in policy directed towards fostering private R&D. Similar to the exercise in this chapter, a starting point for individual country analysis could be a breakdown of the R&D position relative to the OECD average into a sector composition effect and an intrinsic effect. Table 5.7 shows both effects for various OECD countries. A challenge for each individual country is to decompose the intrinsic effect. This chapter provides tools to accomplish such a breakdown based on empirical evidence (see Table 5.5).

Policy options for governments to raise private R&D intensity revolve around improvements of the intrinsic effect. In the Netherlands the intrinsic R&D shortfall is mainly due to low R&D expenditure of foreign affiliates. An excellent investment climate is essential for attracting foreign investments. Key factors in improving the R&D investment climate are, among other things, the availability of (high-quality) knowledge workers, more specific the amount of scientists and engineers, and an excellent (public and private) knowledge base (see Griliches, 1992; Ogawa, 1997). The location factors of international R&D investments are examined more comprehensively in Chapter 7 of this thesis.

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ANNEX 1. Contribution of fast-growing firms

In the business community fast growth (after the start-up phase) is the second stage in the entrepreneurial process. It appears that fast-growing businesses invest more in human capital, pursue a more active innovation strategy, introduce new products more often and spend more on R&D (see Baljé and Waasdorp, 1998). An international benchmark study by EIM shows that the quantity of fast-growers in the Netherlands dropped from 23% (share of total business population with 50-1,000 employees) in 1995-1998 to 18.1% in 1998-2001 (see Bosma and Verhoeven, 2004).[87] Data on fast-growing businesses in other countries in 1998-2001 are only available for Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the UK and the US. Even though this is a relatively small group, it can be used to compute a reasonably representative OECD average. The OECD average is determined by the total number of firms in the total business population per country.[88] The calculation shows that 25% of all businesses (50-1,000 employees) within the OECD average were fast growers in 1998-2001. The percentage in the Netherlands was 18%. Thus, the Netherlands was lagging behind the OECD average by 7 percentage points.

Based on survey results for 276 firms, Baljé and Waasdorp (1998) find that R&D expenditure of fast-growing firms as a percentage of turnover is approximately 40% higher than in non-fast-growing companies.[89] In 2002, 57% of private R&D intensity in the Netherlands was conducted by businesses with 50-1,000 employees.[90] Assuming that this percentage does not deviate from 2001, we can calculate that total R&D expenditure of businesses with 50-1,000 employees was approximately € 2.7 billion. In 2001 the number of fast-growing firms in the Netherlands among businesses with 50-1,000 employees amounts to 1,648 firms (18% of a total of 9,105 firms). The complement of this amount is the number of non-fast-growing businesses (7,457 firms). As fast growers conduct 40% more R&D than non-fast growers, we need to compute 'R&D equivalents'. This is done by multiplying the number of fast growers by 1.4 (i.e. fast-growing firms conduct 40% more R&D than non-fast growers). Consequently, the average R&D expenditure per R&D equivalent in 2001 is € 275,700.

If the proportion of fast-growing firms in the Netherlands would be equal to the OECD average (25% instead of 18.1%), the number of fast-growing firms in absolute terms would be 2,264 (as opposed to 1,648). In turn, the number of non-fast growers would be lower (6,841 instead of 7,457). In this hypothetical situation R&D expenditure of fast growers would be roughly € 873

[87] Fast-growing businesses are defined as firms which realised an increase in turnover of at least 60% over a three-yearly period.

[88] In order to determine the weighted OECD average, figures on the number of businesses per country were kindly made available by Wim Verhoeven of EIM. For Europe, we used data from the Eurostat database, for the US the data originates from the 'Census of Enterprises' of the Bureau of the Census and SBA, and for Japan this was the 'Census of Enterprises' of the official Japanese Bureau of Statistics.

[89] Fast-growing businesses were selected by observing turnover growth in 1992-1996 in compliance with the adjusted 'Birch Index' (see p. 10, box 1.1 in Baljé and Waasdorp, 1998).

[90] This share is an estimate by Gerhard Meinen of Statistics Netherlands.

million (2,264 × (1.4 × 275,700)). R&D expenditure of the non-fast growers would be € 1.8 billion. All in all, total R&D expenditure among businesses with 50-1,000 employees is approximately € 2.8 billion. R&D expenditure in the other size categories is € 2 billion. Hence, in the hypothetical situation where the amount of fast-growing firms in the Netherlands would be similar to the OECD average, the R&D expenditure would amount to € 4.8 billion – or 1.12% of the GDP. The conclusion is that the lower number of fast-growing firms contribute 0.02 percentage points (= 1.12% − 1.10%) to the Dutch shortfall in corporate R&D.

ANNEX 2. Robustness analysis using an error correction model

This annex presents an additional empirical robustness test. In order to explain the knowledge intensity of the economic structure of an economy, it is important, from a theoretical point of perspective, to take into account the continuing impact of R&D variables on the sector composition over time. In the estimated model of Section 5.2.3, this was done by introducing a lagged dependent variable as an explanatory variable, which captures the dynamics of an impulse of one of the R&D variables on the sector composition towards a long-run (asymptotic) value. Using a lagged dependent variable in panel estimations of levels, however, involves an econometric risk of estimation bias. In this annex, therefore, we conduct a robustness analysis to test if our estimation results in Section 5.2.3 are solid.

First of all, we need to ascertain what type of alternative model we can use to conduct the robustness analysis. An augmented Dickey-Fuller test learns that we are dealing with nonstationary variables. An appropriate way to manipulate nonstationary series is to use first differencing. However, differencing the data is counterproductive, since it obscures the long-run relationship between our dependent and independent variables (see Greene, 2000, p. 790); something which is especially important when trying to explain the (development of the) sector composition effect of a country. A more appropriate model is to use an *error correction model (ECM)*. An error correction model is a dynamic model which allows for simultaneous estimations of both long-run equilibrium values and short-term dynamics. For further reading on error correction models see Greene (2000, p. 733 ff), Wooldridge (2004, p. 620 ff) and Verbeek (2004, p. 318 and 319).

We estimate the following error correction model:

$$\Delta STR_{i,t} = \beta(\Delta INT_{i,t-1}) + \xi(\Delta PUB_{i,t-1}) + \phi(\Delta LAB_{i,t-1}) + \lambda\left[STR_{i,t-1} - (\alpha + \tau(INT_{i,t-2}) + \upsilon(PUB_{i,t-2}) + \delta(LAB_{i,t-2}) + \sum_i f_i DUM_i) \right] + \varepsilon_{i,t} \tag{A.1}$$

In equation (A.1), *STR* represents the sector composition effect as a percentage of total value added, *INT* denotes the intrinsic effect as a percentage of total value added (private R&D intensity adjusted for the sector composition effect), *PUB* indicates the difference in public R&D intensity between the Netherlands and the OECD average[91], *LAB* represents the relative unit labour costs vis-à-vis competitors in other OECD countries (expressed as a percentage deviation from 1995)[92] and *DUM* represents country dummies. The indicia *i* and *t* refer to

[91] Public R&D intensity is defined as public R&D expenditure (comprising R&D expenditure of higher education institutions and public research institutes) as a percentage of total value added. The data were taken from OECD Main Science and Technology Indicators, 2004-2.

[92] The relative unit labour costs relate to manufacturing industries. The data are taken from OECD Economic Outlook database.

respectively countries and years. The estimated values of β, ξ, ϕ represent the short-term dynamic impact of respectively the variables *INT*, *PUB* and *LAB* on the sector composition effect. The term between straight brackets captures the long-run equilibrium effect of our explanatory variables on the sector composition: τ (*INT*), υ (*PUB*) and δ (*LAB*). The coefficient λ embodies the error correction mechanism that should be significantly negative in order to push short-term deviations back towards their equilibrium values. The three explanatory variables – *INT*, *PUB* and *LAB* – have been included with a lag of one year in the dynamic part of the equation and a lag of two years in the part covering the long-run relationships.[93] Table A.1. shows the estimation results using panel data for 18 countries[94] over the period 1987-2001.

Table A.1 Estimation results of error correction model

	Coefficient	Std. error	t-value	P-value
α	-0.670	0.184	-3.64	0.00
β	0.214	0.119	3.96	0.00
ξ	0.254	0.119	2.13	0.03
ϕ	-0.002	0.000	-3.58	0.00
λ	-0.151	0.048	-3.14	0.00
τ	0.717	0.322	2.23	0.03
υ	1.762	0.609	2.89	0.00
δ	-0.004	0.002	-1.67	0.09
R^2	0.35	Durbin-Watson	1.74	
Adjusted R^2	0.30			
Number of observations	209			

Explanation: Using a one-sided t-test with a 95% confidence interval, the critical value to reject the hypothesis that no significant correlation exists between the sector composition effect and our public R&D variable lies at 1.65 (in case of more than 120 observations). Tested two-sided, the variable is significant at 10%.

Our error correction term λ proves to be significant and negative, which means that out-of-equilibrium inferences of the independent variables in the short term are pushed towards the actual values in the long run. This implies that, conversely, the Granger representation theorem (Granger, 1983; Engle and Granger, 1987) holds and the series are necessarily cointegrated (see Verbeek, 2004, p. 319).

The error correction model shows more or less equal results as presented in Section 5.2.3 (compare Table 5.1 and Table A.1). All estimated long-run coefficients (τ, υ, δ) prove

93 Using lags of one year instead of two years for *INT*, *PUB* and *LAB* in the part that relate to the long-run relationships does hardly alter the estimated long run coefficients τ, υ and δ.

94 These 18 countries are Australia, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Italy, Japan, Korea, the Netherlands, Norway, Poland, Spain, Sweden, the UK and the US

significant and show magnitudes that approximate the coefficients found in Table 5.1.[95] Based on the results from the error correction model, we can conclude that the estimation results presented in Section 5.2.3 are solid and that bias of the coefficients remains limited, despite the inclusion of a lagged dependent variable in the specification.

[95] In contrast to the estimations in Table 5.1 of Section 5.2.3, the effect of private and public R&D are estimated independently. Estimated simultaneously, the joint coefficient for both R&D variables becomes 1.08, which is almost equal to the elasticity of 1.16, estimated in Table 5.1 using equation (5.2).

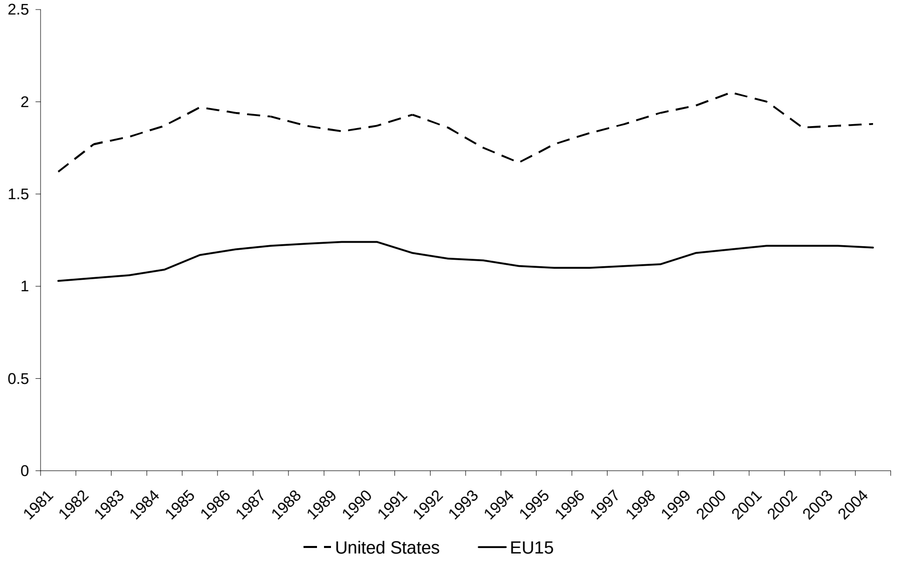
CHAPTER 6

Disentangling the R&D shortfall of the EU vis-à-vis the US

6.1 INTRODUCTION

It is broadly accepted that business research and development (R&D) is an important engine for productivity growth (e.g. Baumol, 2002; Jones, 2002; Chapters 3 and 9 of this thesis). A generally recognised problem is that the European Union lags behind the US to a considerable extent (see Figure 6.1).

Figure 6.1 Private R&D expenditures as a percentage of GDP



Source: OECD, Main Science and Technology Indicators, 2006-2.

As a reaction, European political leaders formulated two major innovation and R&D objectives. The first is the ‘Lisbon ambition’, in which the EU aims to become the most dynamic and competitive knowledge economy in the world by 2010. The second (and more specific) policy objective is the ‘Barcelona target’, which commits the EU to raise its R&D expenditure to 3% of GDP, two-thirds of which should be financed by the private sector (European Council, 2002; European Commission, 2002). Within the context of these European policy objectives, the R&D gap should be narrowed significantly.

The causes of the private R&D shortfall of the European Union vis-à-vis the US merit further investigation. Even if the deficit is mainly of an intrinsic nature, it would be difficult to improve the R&D performance of the EU using many of the well-known instruments. If the sector composition of the economy plays a major role in explaining the R&D gap between the EU and the US, however, the policy debate concerning how to narrow the existing R&D deficit would be even more complicated. Although the sector composition of a country is not completely exogenous (see Chapter 5), such a situation would require even greater effort and more time to enhance the intrinsic R&D position of the EU15 in order to catch up with US R&D standards.

This chapter uses the methodology developed by Erken and Ruiter (2005, also see Chapter 5 of this thesis) to disentangle differences in business R&D between countries or regions. The structure of this chapter is as follows. In Section 6.2, the R&D gap between the EU15 and the US is broken down into a sector-composition effect and an intrinsic effect. Section 6.3 discusses the causes of the intrinsic R&D shortfall of the EU relative to the US. In Section 6.4, we provide an overall decomposition of the private R&D shortfall in the EU15 vis-à-vis the US.

6.2 SECTOR COMPOSITION EFFECT AND INTRINSIC EFFECT

When comparing the R&D intensity between the EU15 and the US two effects should be taken into consideration: a *sector composition effect* and an *intrinsic effect*. The *sector composition effect* compares the share of knowledge-intensive industries within the overall economic structure between countries or regions. If the share of knowledge-intensive industries within the total economy of Country *X* is larger than it is in country *Y*, the sector composition effect is positive for Country *X* and negative for Country *Y*. The *intrinsic effect* is the complement of the sector composition effect and represents the within-industry effect. A negative intrinsic effect implies that companies within a given industry spend less on R&D than their foreign counterparts in the same sector.

Formula (6.1) is used to calculate both effects (see Van Velsen, 1988; Hollanders and Verspagen, 1998, 1999; see Chapter 5):

$$RDI_X - RDI_Y = \sum_i RDI_{Y,i}(P_{X,i} - P_{Y,i}) + \sum_i P_{X,i}(RDI_{X,i} - RDI_{Y,i}) \tag{6.1}$$

In equation (6.1), *RDI* represents the extent of private R&D intensity (measured by expenditures on R&D as a percentage of gross value added); *P* stands for the share in value added, *i* indicates the sector; *X* denotes country/region and *Y* the country/region with which country/region *X* is compared. In our calculations, the weighted EU15 average represents country *X* and the US country *Y*.[96] The *sector composition effect* is the first term after the equals sign, and the *intrinsic effect* is the term after the plus sign.

Industry data on value added and R&D expenditure are taken from the GGDC 60-Industry Database, the OECD STAN database and the OECD ANBERD database. The data were configured by the Dutch Ministry of Economic Affairs. The dataset used in this chapter covers:

- 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, the UK and the US;
- 36 industries;
- the period 1987-2003, i.e. 17 years.

In Figure 6.2, the difference between the US and the EU15 in terms of business R&D is broken down into a *sector composition effect* and an *intrinsic effect*. This chapter considers the private R&D gap between the US and the EU15 in 2002. The total R&D gap presented in Figure 6.2 deviates slightly from the total R&D gap plotted in Figure 6.1. The difference in business R&D intensity between the EU15 and the US is 0.74 percentage points based on data from the Main Science and Technology Indicators, whereas calculations based on the OECD STAN, OECD ANBERD and GGDC data show a difference of 0.63 percentage points. This difference is due to from the fact that gross value added is expressed at basic prices in the industry-level calculations (i.e. Figure 6.2), whereas the gross domestic product at market prices was used as a denominator for the private R&D intensity in figures based on data from the OECD Main Science and Technology Indicators (Figure 6.1).

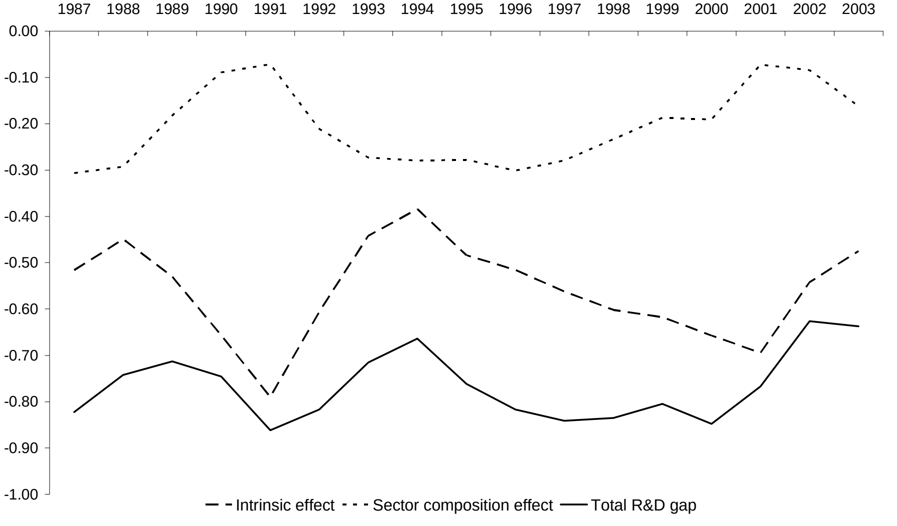
Figure 6.2 shows that differences in the sector composition of Europe and the US provide only a marginal explanation for the R&D divergence between the two countries. In 2003, the sector composition was responsible for roughly 25% of the total R&D shortfall of the EU vis-à-vis the US. The remaining 75% of the European R&D gap is intrinsic in nature.

Breaking down the R&D difference between *individual* EU countries and the US results in a more differentiated picture. Some countries do show a strong sector composition effect (either positive or negative), while other countries reveal no effect. Furthermore, the sector composition effect is quite volatile over time in some cases. Because the differences between

[96] Unless otherwise mentioned, the weighted EU averages in this chapter are based on value added shares.

countries equal out at the aggregate level, however, we can conclude that the size of the sector composition effect for the EU as a whole is limited.

Figure 6.2 Difference in private R&D intensity between the EU15 and the US (EU15-US), 1987-2003



Source: Authors' calculations based on the OECD ANBERD and STAN databases and the GGDC 60-Industry Database.

Just as is the aim of this chapter, the European Commission (2007) has recently conducted a study to gain more insight into the causes behind the private R&D gap between the European Union and the US. The Commission states that with regard to the manufacturing sector (pp. 28 and 29): *'structural differences seem to be at least as important as the 'intrinsic effect' (i.e. sector-specific R&D intensities)'*. This finding is in accordance with our own calculations: within manufacturing the knowledge-intensity of industries (e.g. R&D intensity) does not seem to differ much between the US and the EU. Rather, the larger size of especially the US' ICT sector explains the difference in R&D expenditure between the manufacturing sectors in the US and the EU.

The European Commission, however, disregards the service sector in their analysis, because of comparability problems with R&D data of the services sector between the US and the EU (European Commission, 2007, p. 22). Based on work by the OECD (2005) and the National Science Foundation (2005) on differences in the methods used in the US and the EU to classify R&D by industrial activity, the Commission stipulates that there are much statistical drawbacks that complicate international R&D comparisons on an industrial level. The European Commission (2007, p. 24, footnote 14) estimates that at least 33% of the private R&D intensity in the services sector within the US is misallocated and instead should be ascribed to the manufacturing industry.

Despite the severity of these statistical drawbacks, there is no valid argument to ignore the service sector entirely. First of all, a sector composition analysis is not complete if the services sector is excluded. Most important, even if 33% or more of the private R&D expenditure in the US' service sector is wrongly allocated, there still remains a large intrinsic gap between R&D in the European services sector and the services sector in the US. In addition, reallocating R&D expenditure from US' services to the manufacturing sector would only marginally alter the picture sketched by Figure 6.2. Indirectly, the negative sector composition effect of the EU vis-à-vis the US would become slightly higher, which can be derived from equation (6.1). Because of relatively small sector composition differences in the manufacturing sector between the EU and the US ($P_{EU,i} - P_{US,i}$), combined with higher R&D intensities of the individual industries in the US ($RDI_{US,i}$), the negative sector composition effect would rise somewhat. At the same time, the redistribution of R&D expenditure from the services sector to manufacturing would result *for the larger part* in a relocation of the negative intrinsic effect from the services sector to the manufacturing sector. The most important negative side effect of the misallocation of R&D is that the specific sectors causing the total negative intrinsic effect are not known. In any case, reallocation of R&D investments from the US' services sector to the manufacturing sector would still result in a large negative intrinsic effect for the EU and, consequently, a relatively limited negative sector composition effect.

The weak explanatory power of the sector composition effect implies that, in general, the European Union cannot ascribe its poor R&D position to factors that are largely exogenous in the short term (i.e. the structure of the European economy). The intrinsic effect is clearly more sensitive to governmental policy than the sector composition effect. This is apparently good news for policymakers. The following section considers the elements of the intrinsic effect.

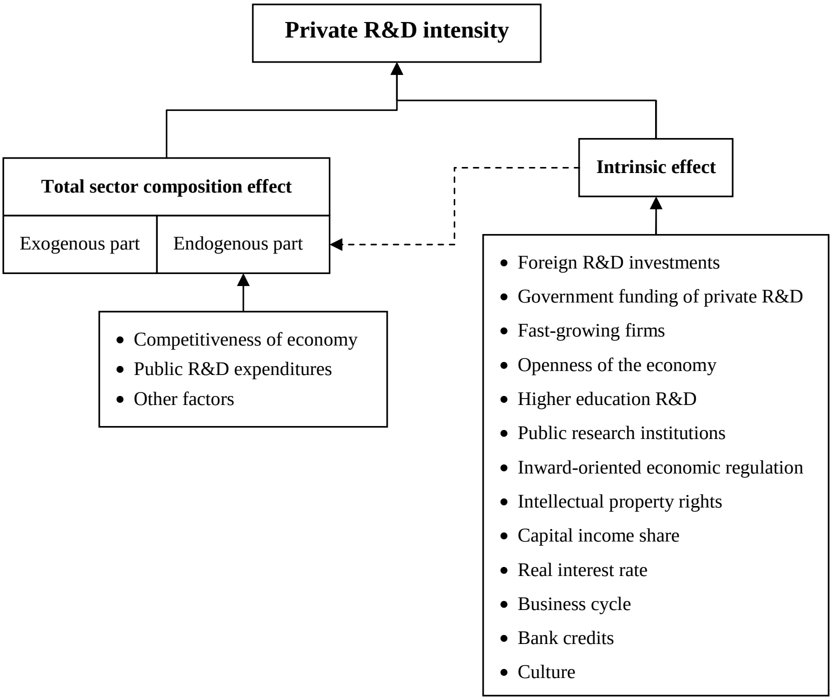
6.3 DISENTANGLING THE INTRINSIC EFFECT

6.3.1 Theoretical framework and methodology

In the previous section, we showed that the R&D shortfall of the EU15 vis-à-vis the US can be largely attributed to the negative intrinsic position of the EU15. In this section, we elaborate on possible causes of this negative intrinsic effect. A country's intrinsic position depends upon a large spectrum of determinants (e.g. the intensity of internationalisation that a country is facing with regard to R&D, the institutional environment and the level of government support for stimulating business R&D). Figure 6.3 shows a theoretical framework of the determinants of private R&D from a macro level of perspective. The figure shows that total private R&D

intensity in a country is dependent on both the sector composition effect and the intrinsic effect. The sector composition itself is not completely exogenous and is partly dependent on the intrinsic effect itself (see Chapter 5 for more information on this relationship). This implies that the technological competitiveness of a country is reflected in its economic structure.[97] A positive sector composition effect is not, or at least not solely, the consequence of more or less coincidental and historically determined circumstances, but the result of successful competition on technology markets.

Figure 6.3 Theoretical framework of the determinants of private R&D



In the empirical literature, the impact of various factors on the intrinsic effect is generally estimated using an econometric model, which often has the following functional form:

$$RD_{i,t} = \alpha_i + \beta_i X_{i,t} + \delta_i D_{i,t} + e_{i,t} \tag{6.2}$$

[97] Besides the impact of the intrinsic effect on the sector composition effect, the influence of public R&D and price competitiveness was made explicit in the model by Erken and Ruiter (2005, see Chapter 5 of this thesis).

In equation (6.2), $RD_{i,t}$ represents the R&D intensity of countries, firms or industries (i) at time t. $RD_{i,t}$ is modelled as a function of a constant term α_i, a vector of explanatory variables $X_{i,t}$ and a dummy variables (firm-, country- or industry-specific fixed effects) $D_{i,t}$. The error term is denoted by $e_{i,t}$.

If equation (6.2) is estimated at a the macro level, it is important to include the sector composition effect as a separate variable within vector $X_{i,t}$. On lower levels of aggregation, the impact of the sector composition effect is irrelevant. If the sector composition effect is properly accounted for, $X_{i,t}$ embodies the various mechanisms that influence the intrinsic effect, e.g. foreign R&D investments, government stimulation of R&D and institutions.

Because there is no research available which studies the impact of all determinants of private R&D simultaneously, we adopt a ‘partial approach methodology’ to break down the intrinsic effect between countries/regions. This approach unfortunately does have a number of disadvantages. For example, the elasticities between studies that examine the impact of certain determinants of business R&D vary and are not always consistent. As a consequence, a certain level of uncertainty accompanies any partial quantification based on these elasticities. To obviate the problem of arbitration as much as possible, Erken and Ruiter (2005, see Chapter 5 of this thesis) conducted an assessment of the empirical literature dealing with the determinants of business R&D. This assessment led to a selection of studies that are considered to provide the most reliable insights into the impact of various determinants of private R&D expenditure. With regard to certain determinants, however, the literature remains scarce and complicated.

To bridge these empirical gaps, we use results from an empirical study by Donselaar and Segers (2006) – which was carried out parallel to the study by Erken and Ruiter – in which the impact of many determinants of business R&D has been examined in a simultaneously estimated model. The study uses panel data covering 20 OECD countries over a period of 31 years. A major benefit of the study by Donselaar and Segers is that so-called *omitted variable bias* is limited, because their model contains many variables (more than most other empirical studies explaining business R&D). Omitted variable bias means that when an explanatory variable (*X1*) is omitted from an econometric specification and correlates with both the dependent variable and a variable that is included in the specification (*X2*), the coefficient of *X2* is biased (e.g. Wooldridge, 2003, pp. 89 ff; Verbeek, 2004, pp. 55 ff).[98] The problem of omitted variable, fir instance, could arise when assessing the effect of the *business cycle* on the R&D intensity (see Section 6.3.8). Because *X1* (in this case *profitability*) is correlated with both *X2* (*business cycle*) and the R&D intensity, the effect of the *business cycle* is biased when *profitability* is omitted from the econometric specification. We indeed observe that the coefficients estimated by Donselaar and Segers represent effects that are more moderate than those found in other studies that estimate less advanced models.

[98] The coefficient is overestimated in case of positive correlation and underestimated in case of negative correlation.

There are some factors of the intrinsic effect that are hardly dealt with in the empirical literature, e.g. the impact of culture, the availability of human capital and the size of countries.[99] These determinants were necessarily omitted in this chapter, because of either data problems or contradictory empirical evidence. For example, the impact of human capital on R&D expenditure is insignificant in most empirical studies (see Kanwar and Evenson, 2001; Reinthaler and Wolff, 2002).[100] Because we could not include all determinants of private R&D in this study, there could be some overestimation or underestimation of the intrinsic shortfall of the EU. This, in turn, could have consequences for the overall decomposition of the R&D gap. Nevertheless, we believe that most of the important factors of private R&D intensity are included in this study, allowing us to provide a fairly clear picture of the causes behind the observed R&D shortfall of the European Union vis-à-vis the US in 2002. Further research is needed to expose the importance of the omitted determinants of business R&D.

Another disadvantage of the partial approach is that it does not take into account the interaction effects between determinants that have a multiplicative relationship with business R&D. In Annex 1, we performed a test to examine the possibility of significant interaction effects between these determinants. The results show that the sum of the interaction effects between determinants that have a multiplicative relationship with business R&D are quite low (0.01 percentage point in total). This interaction effect is included in the overall decomposition in Section 6.4.

Despite the shortcomings of the partial approach adopted in this chapter, we believe that it is the best methodology available for breaking down the intrinsic R&D differences between countries or regions. The remainder of Section 6.3 is as structured as follows. In Sections 6.3.2 to 6.3.4, the contribution of determinants is examined that have an additive relationship with business R&D. In Sections 6.3.5 to 6.3.8, we deal with determinants that have a multiplicative relationship with business R&D (e.g. the openness of the economy and inward-oriented economic regulation). The partial contribution of each determinant is incorporated in the decomposition table of Section 6.4.

6.3.2 Internationalisation of R&D

When analysing the effect of internationalisation of R&D activities on the R&D gap between the EU and the US, two types of R&D flows should be taken into consideration: outward and

[99] For example, Van der Horst *et al.* (2006) show that large countries (in terms of GDP) spend more on public R&D than small countries do. The same counts for public funding of private R&D, although there is apparently no relationship between the public funding of innovative SMEs and the size of the economy.

[100] Reinthaler and Wolff (2002) find an insignificant effect of human capital (i.e. the share of highly educated persons within the total population) in a fixed effects model and a model with random effects. In estimations without fixed effects, the researchers do find a significant effect of human capital, indicating that human capital arguably could have a positive effect on R&D in the cross-sectional dimension. Panel data estimations without fixed effects, however, are vulnerable to estimation bias, because of possible unobserved heterogeneity (Wooldridge, 2003, p. 439; Popkowski Leszczyc and Bass, 1998). We therefore perceive these empirical outcomes with some caution.

inward R&D investments. Outward investments encompass the R&D activities of domestic firms conducted abroad.[101] Inward investments represent the opposite.[102] The OECD *Activities of Foreign Affiliates* (AFA) database provides data on inward and outward R&D. The availability of data on outward R&D is poor, complicating an assessment of the role of outward R&D as an explanation for the R&D gap between the EU15 and the US. In contrast, the inward R&D database does provide sufficient data for this purpose.

The AFA database contains data on the inward R&D investments of nine EU15 countries: Finland, France, Germany, Ireland, the Netherlands, Portugal, Spain, Sweden and the UK. These countries account for over 80% of total R&D expenditure in the EU15. This subset of countries sufficiently represents the R&D expenditure of foreign affiliates in the EU15. However, the inward R&D investments in the EU cannot simply be determined by taking the sum of the inward R&D investments of the nine individual EU countries. These investments include investments between the individual EU countries, which should not be considered as inward R&D investments of the EU15 as a whole. We must adjust total inward R&D investments of the EU for these 'intra-EU R&D investments'. This can be accomplished by considering only the inward R&D investments originating from non-EU countries (e.g. Japan, Canada and the US).

Unfortunately, no data are available on the origin of *total* inward R&D investments. The origin of the inward R&D investments in the *industry sector* can be used as an alternative. These R&D investments account for the larger part of all inward R&D investments; their origin can therefore be considered a good substitute for the origin of total R&D investments. From these data, we can derive that 52.4% of the sum of industrial inward R&D in the nine countries originates from outside the nine EU countries. The sum of the *total* inward R&D investments of all nine countries is multiplied by 0.524 to adjust for intra-EU R&D investments. The same method is applied for correcting the export and import data for the EU, which are used to adjust inward R&D data for the openness of the economy (see below and Chapter 5, Section 5.3.2).[103]

The role of openness of the economy

Inward R&D investments are more important in small, open economies than they are in large, closed economies. In general, taking part in global trade is more important for small economies than it is for large ones. For example, studies by Alesina and Wacziarg (1998) and by Ades and Glaesser (1999) show that small economies are more open than large economies. We expect this

[101] Definition from the OECD (2004, p. 11): *"For outward investment, in principle, the ultimate host country should be considered, but if it is difficult to identify it, the concept of "immediate host country" can be used".*

[102] Definition from the OECD (2004, p. 11): *"For inward investment, the geographical origin of the foreign affiliate corresponds to the home country of the parent company. In principle, the ultimate beneficial owner (UBO) should be considered, but given that some investments are carried out through holding companies or affiliates different from that in which the parent company is located, it is difficult to identify the initial investor. In this case, the country of origin is that of the 'immediate controller'."*

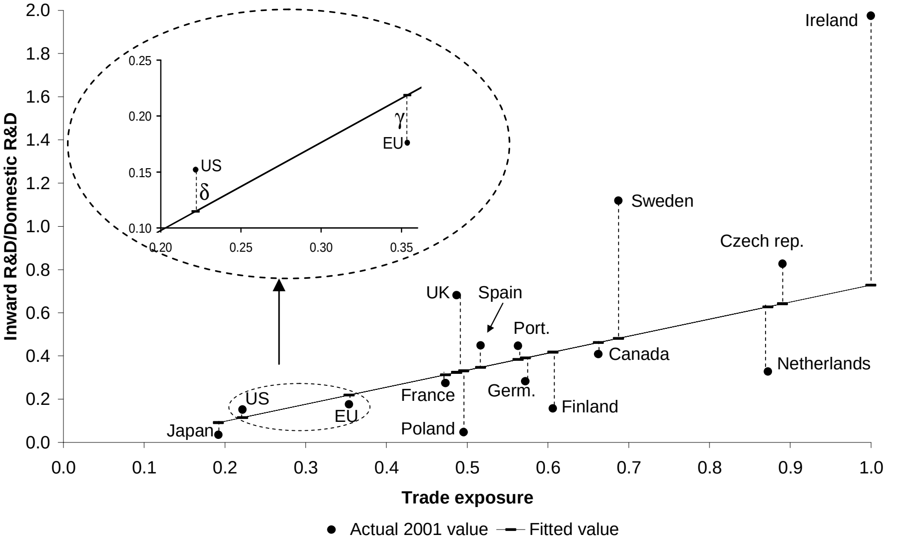
[103] With regard to exports and imports, the shares originating from outside the EU are 56.5% and 58.6% respectively. Data for exports and imports are extracted from the Eurostat External Trade database.

to apply to the share of foreign R&D in total R&D investments as well. This share should thus naturally be higher in open (and small) economies than it is in relatively closed (large) economies.

In this chapter we use *exposure to foreign trade*, as developed by Bassanini *et al*. (2001, p. 25), as an indicator for the openness of an economy. Calculating this indicator involves taking the sum of the export intensity and the import penetration of each country.[104] To account for the openness of the economy, we use the results of the econometric analysis from Chapter 5. In this analysis the ratio of inward R&D investments as a share of domestic R&D investments is related to the trade exposure indicator from Bassanini *et al.* (2001).

Contribution of inward R&D investments to the R&D gap between the EU and the US
The results from the econometric analysis conducted in Chapter 5 enables us to determine the contribution of inward R&D investments to the private R&D gap between the EU and the US.

Figure 6.4 Surpluses and shortfalls in the ratio of inward R&D relative to domestic R&D, 2001



Source: Authors' calculations based on the OECD AFA database, Main Science and Technology Indicators 2006-2, OECD Economic Outlook and the Eurostat External Trade database.

[104] Export intensity is measured by the ratio of total exports to GDP. Import penetration is calculated by the ratio of total import to domestic sales (GDP + total imports – total exports) multiplied by the inverse of the export intensity.

First, we ascertain how much foreign R&D investment the EU and the US should attract in order to reflect the openness of their economies. These 'fitted values' are represented by the solid line in Figure 6.4. The dotted lines represent surpluses and shortfalls in attracting foreign R&D by countries in 2001.

The ratio for the EU in 2001 (17.6%) was only marginally lower than the corresponding fitted value (21.9%) This means that, taking the openness of the economy into account, the EU attracted somewhat too little foreign R&D in relation to domestic R&D: 4.3 percentage points. For the US, the results are different: the fitted value from the regression was 11.5%, whereas the actual value in 2001 was 15.2%. The US attracted 3.7 percentage points more foreign R&D in relation to domestic R&D than could have been expected considering the openness of its economic structure.

The next step is to calculate the contribution of the shortfall and the surplus of inward R&D investments in respectively the EU and the US, in order to explain the private R&D gap between them (see Box 6.1). Summing up, 0.11 percentage point (0.05 + 0.06, the sum of γ and δ in Figure 6.3) of the R&D gap between the EU and the US can be explained by the relative shortfall and surplus of the EU15 and the US, respectively, in attracting foreign R&D.

Box 6.1 Contribution of inward R&D investments

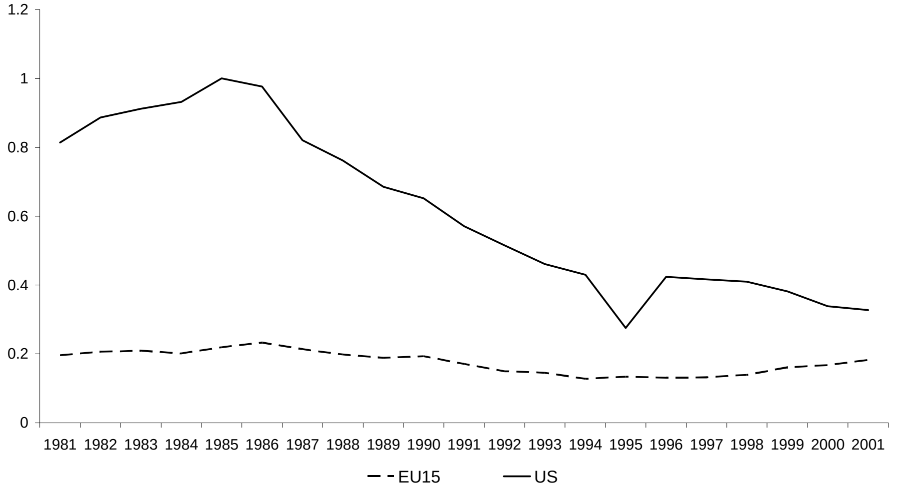
In 2001, the inward R&D intensity in the EU was 0.21% (100% × (inward R&D/GDP)). This means that an increase of the ratio of inward R&D to domestic R&D from 17.6% to 21.9% (fitted value) raises the inward R&D intensity to 0.26% ($\Rightarrow$ (0.219 / 0.176) × 0.21). In addition, the shortfall in foreign R&D investments in the EU has a negative effect on the total R&D intensity of 0.05 percentage points (0.26% – 0.21%), illustrated by γ in Figure 6.3. For the US, the same calculations can be conducted. The actual foreign R&D intensity of the US was 0.26% in 2001; a decrease from 15.2% to 11.5% (fitted value) of the ratio of inward to domestic R&D investments would result in a decline of the inward R&D intensity to 0.20% ($\Rightarrow$ (0.115 / 0.152) × 0.26). Given the openness of the US economy, the surplus of inward R&D investments ultimately has a positive effect of 0.06 percentage points on the private R&D intensity of the US, illustrated by δ in Figure 6.3.

6.3.3 Government funding of private R&D

Business R&D can be funded by the government in two different ways (Guellec and Van Pottelsberghe, 2003). The government can finance business R&D directly by extending subsidies or R&D credits, or by placing R&D orders. Another way to stimulate business R&D is to provide R&D tax incentives.

The multiplier of government R&D incentives on business R&D can be fixed at 1.0 (see e.g. Hall and Van Reenen, 2000; Lichtenberg, 1984, 1987 and Scott, 1984). This means that one euro of additional R&D stimulation by the government – whether it embodies a R&D subsidy, fiscal R&D incentive or R&D order – leads to one additional euro in R&D by businesses.

Figure 6.5 Government funding of private R&D as a percentage of the GDP in the EU15 and the US, 1981-2001 ($PPP, constant prices of 1995)



Sources: Authors' calculations based on data from the OECD beta index, the OECD Economic Outlook no. 74 and the OECD Main Science and Technology Indicators, 2004-2.

Data on the non-fiscal component of government funding of R&D is taken from the OECD Main Science and Technology Indicators. Data on international fiscal R&D incentives are derived from the OECD beta index (see Warda, 1996, 2001). Figure 6.5 shows the total government funding of R&D in the EU15 and the US over the period 1981-2001, expressed as a percentage of GDP. These figures encompass all government funding of private R&D, including fiscal R&D tax incentives, R&D subsidies/credits and R&D orders commissioned by the government (e.g. in the military industry). The plot clearly shows that, in 2002, the overall government funding of private R&D in the US was higher than in the EU15. The shortfall in European business R&D consequently explains 0.14 of the total gap in European business R&D.[105]

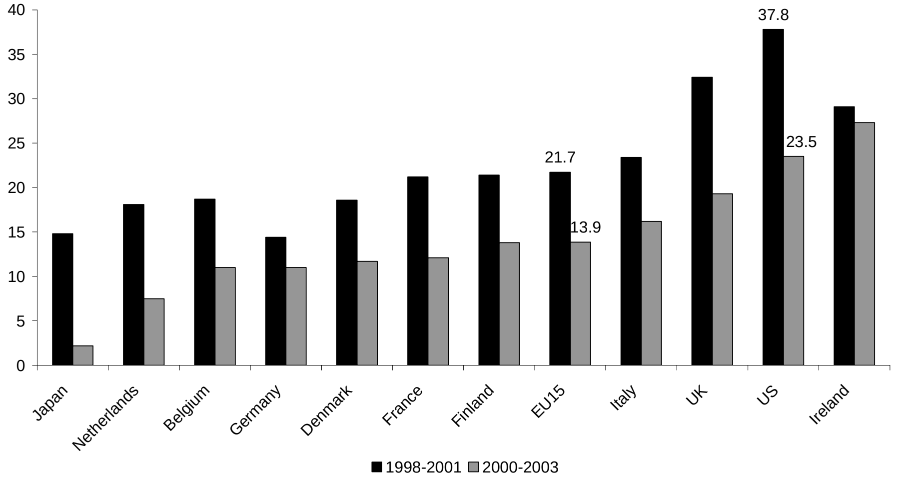
6.3.4 Fast-growing firms

Fast-growing firms are more innovative than non-fast-growing firms. These 'gazelles' invest more in human capital, pursue a more active innovation strategy, introduce new products more often and spend higher amounts on R&D. Baljé and Waasdorp (1999) estimated that fast-growing firms spend approximately 40% more on R&D as a percentage of their turnover compared to their non-fast-growing counterparts (43% more on process development and 38%

[105] Because of minor differences in rounding off, subtracting percentages in this chapter does not always correspond to the presented percentage point difference between them.

more on product development). Differences in the share of fast-growing firms between the EU and the US could explain part of the European R&D gap.

Figure 6.6 The share of fast-growing firms with 50-1000 employees (% of all firms with 50-1000 employees), 1998-2001, 2000-2003



Source: De Jong-'t Hart and Verhoeven (2007).

EIM reports annually on the prevalence of fast-growing firms as a share of firm population with 50-1000 employees. Data are available for Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, the UK and the US. The data are presented over four-yearly periods. We use figures for the period 2000-2003, as this period includes the year 2002, which is the year of observation for our decomposition analysis. As shown in Figure 6.6, the share of fast-growing firms in the EU is lower than in the US (13.9% versus 23.5%).[106] Calculations in Annex 2 illustrate, however, that this lower share only explains a small part of the gap in corporate R&D of the European Union, i.e. 0.03 percentage points.

6.3.5 Openness of the economy

In Section 6.3.2, we already addressed that the openness of the economy (in terms of openness to trade) has important implications for business R&D through the internationalisation of R&D. The openness of the economy also has an important direct effect on the level of private R&D expenditure (see, e.g., Helpman, 2004; Falk, 2006). First, firms operating in open economies are more exposed to competition than firms in relatively closed economies. Because innovation is

[106] The EU15 figure represents a weighted average based on the total number of fast-growing firms within the size class of 50 to 1,000 employees.

important to remain competitive, and because R&D expenditure is one of the main drivers of innovation, it is reasonable to expect that more openness leads to a higher level of R&D expenditure. For example, Smulders and Van de Klundert (1995) argue that import competition encourages investments in R&D by simultaneously reducing mark-ups and increasing the level of domestic concentration. Second, a higher level of openness to foreign trade opens up possibilities to operate on larger export markets and exploit the results of R&D and innovation on a larger scale. Pires (2006) provides evidence that firms located in countries with more demand (i.e. a larger market) become more competitive, because they have strong incentives to conduct R&D.

The indicator for the exposure of countries to foreign trade is based on the previously-mentioned variable *exposure to foreign trade* (see Section 6.3.2). In line with Bassanini *et al*. (2001), we adjust this openness variable for country size. Small countries are more exposed to foreign trade than larger countries, regardless of their trade policies or competitiveness, because the share of small economies within total world economy is by definition smaller. In large countries, competitive pressure is due to domestic competition across regions. Annex 1 presents calculations how to determine the contribution of openness to the R&D gap between the EU15 and the US.[107] The openness variable contributes positively to the intrinsic R&D position of the EU by a marginal 0.02 percentage points.

6.3.6 Public R&D

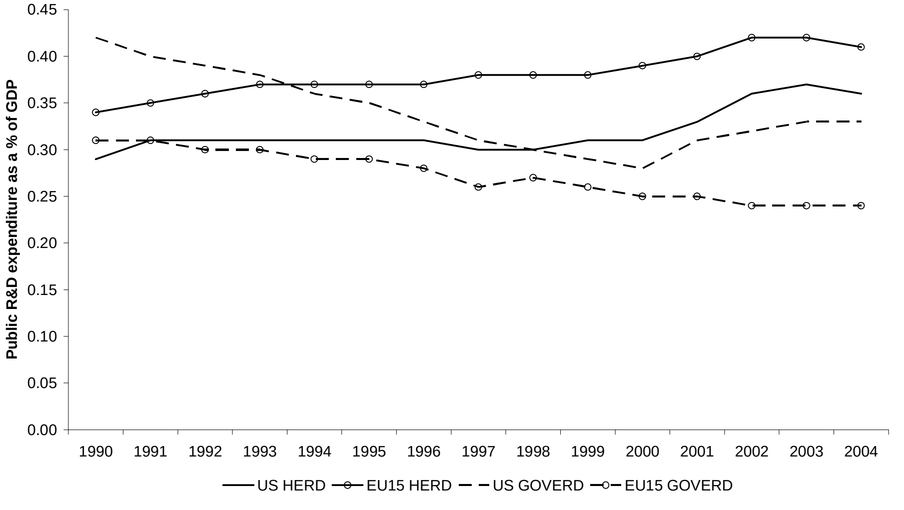
A country's level of public R&D expenditure has a direct influence on its private R&D expenditure. Public R&D is conducted by universities (Higher Education Expenditure on R&D: HERD), as well as public research institutes (Government Expenditure on R&D: GOVERD). A number of studies have examined the effect of public R&D expenditure on private R&D expenditure. Guellec and Van Pottelsberghe de la Potterie (2003) find a negative effect, which implies that public R&D expenditure could be a substitute for a country's private R&D expenditure. It is, however, more plausible that public R&D expenditure and private R&D expenditure are complementary (see European Commission, 2004; Reinthaler and Wolff, 2004; Falk, 2006). The most moderate effect is found in a study by Donselaar and Segers (2006).[108]

Data on public R&D spending is taken from the OECD Main Science and Technology Indicators (2006-2). Figure 6.7 shows the development of the HERD and GOVERD in the EU15 and the US. In 2002, the amount that universities spend on R&D (as a percentage of GDP) is lower in the US than in the EU (0.36% versus 0.42%), while the R&D expenditure of research institutes as a percentage of R&D is higher (0.32% versus 0.24%).

[107] These calculations are based on the elasticity from Donselaar and Segers (2006), who adjusted their openness variable by using volumes and taking the relative size of the economy into consideration.

[108] For example, the estimated effects of public R&D expenditure on private R&D expenditure by the European Commission are exceptionally high: one additional euro spend on R&D by universities leads to an additional 1.3 euros of R&D expenditure by businesses. Similarly, one additional euro of R&D expenditure by research institutes results in an additional 1.1 euros of R&D expenditure by the private sector.

Figure 6.7 Public R&D as a percentage of GDP, EU15 and OECD, 1990-2004



Source: OECD Main Science and Technology Indicators, 2006-2.

By linking these differences in R&D intensity to the elasticities found by Donselaar and Segers (2006), we are able to calculate the contribution of public R&D to the difference in private R&D between the EU15 and the US.[109] The calculations in Annex 1 show that the higher R&D investments by universities in the EU15 has a limited positive effect of 0.01 percentage point on the R&D intensity of the EU15 relative to the US. Conversely, the higher R&D expenditure of research institutes in the US contributes 0.05 percentage point to the negative intrinsic R&D effect of the EU.

6.3.7 Institutions

Two important institutional regimes that have an important impact on innovation and business R&D in countries are the intensity of product market regulation (e.g. state control, competition) and the rigorousness of the intellectual property rights (IPR) regime. A hallmark study by Bassanini and Ernst (2007) examines the impact of product market regulation and IPR on private R&D intensity. As a part of total product market regulation, inward-economic regulation appear sto be negatively correlated with business R&D, whereas a more stringent IPR regime

[109] An estimate using private R&D intensity as the dependent variable results in a semi-elasticity of 0.47 for the effect of R&D by public research institutes (GOVERD) as a percentage of GDP. In the same study, a semi-elasticity of 0.20 was estimated for the effect of university R&D (HERD) as a percentage of the GDP. These semi-elasticities can be transformed into multipliers. One additional euro spent on R&D by public research institutes adds 0.52 eurocents to the level of R&D expenditure by businesses, and one additional euro in R&D spending by universities increases R&D expenditure by firms by 0.22 eurocents.

shows a positive relationship with business R&D. These findings are in accordance with studies by Aghion *et al.* (2001) and Blundell *et al*. (1999): given a reasonable level of intellectual property rights protection that limits the risk of imitation, competition has a beneficial effect on R&D and innovation. Bassanini and Ernst (2007) report semi-elasticities of inward-oriented economic regulation on private R&D intensity ranging between -0.274 and -0.349. Because we consistently use moderate effects to calculate the contribution of each determinant, we fix the semi-elasticity at the lower level of this range (-0.274). The semi-elasticity measuring the effect of IPR on private R&D expenditures varies between 0.528 and 0.664. Donselaar and Segers (2006) find a more moderate effect of 0.72. This direct output elasticity implies that an increase of 1% on the intellectual property rights index – developed by Ginarte and Park, 1997 – leads to an increase of 0.72% in private R&D one year later (the IPR variable was lagged by one year in the econometric analysis by Donselaar and Segers, 2006).

Contribution of economic regulation

The data on product market regulation used by Bassanini and Ernst (2007) originate from a study by Nicoletti *et al.* (1999). The data were gathered by the latter authors in 1999, and they were updated by Conway *et al.* (2005). Annex 3 shows how the product market regulation index is constructed. The PMR indicator consists of 16 low-level indicators. Each of the low-level indicators captures a specific aspect of the regulatory regime. In total, the low-level indicators span most of the important aspects of general regulatory practice, in addition to several aspects of industry-specific regulatory policies (Conway *et al*., 2005). The indicator inward-oriented regulation uses a scale from 0 to 6: a score of 0 indicates a low level of inward-oriented economic regulation, whereas a score of 6 indicates a high level. In 2003, the US has a score of 1.3 on this index, and the EU15 has a score of 2.1.

Annex 1 presents calculations illustrating that, in 2003, the position of the EU15 on inward-oriented economic regulation explains roughly 0.30 percentage points of the total intrinsic R&D shortfall of the EU15 relative to the US. Because inward-oriented economic regulations in the EU explains a significant part of the total R&D shortfall in the EU, it is interesting to identify exactly what aspects of the regulatory regime causes the weak position on this driver of business R&D.

In Table 6.1, the position of the EU15 and the US on the low-level indicators of inward-oriented economic regulation are presented for 2003. Annex 3 provides more information on how the indicator *inward-oriented economic regulation* can be broken down into these sub-indices. The US outperforms the EU15 on each of the low-level indicators. The difference is most prominent on three indicators: *scope of public enterprise sector*, *direct control over business enterprise* and the *use of command & control regulation*. The definitions of these low-level indicators can be found in Conway *et al.* (2005, p. 9). The indicator *scope of public enterprise* measures the pervasiveness of state ownership across business sectors as the proportion of sectors in which the state has an equity stake in at least one firm. The indicator *direct control over business* *enterprise* encompasses the existence of government special voting rights in privately-owned firms, constraints on the sale of state-owned equity stakes, and the extent to which legislative bodies control the strategic choices of public enterprises. The indicator *use of command & control regulation* measures the extent to which the government uses coercive (as opposed to incentive-based) regulation in general, as well as in specific services sectors.

Table 6.1 Low-level indicators of inward-oriented economic regulation, 2003

	Scope of public enterprise sector	Size of public enterprise sector	Direct control over business enterprise	Use of command & control regulation	Price controls	Legal barriers	Antitrust exemptions
EU15	0.8	0.3	0.6	0.6	0.2	0.2	0.4
US	0.4	0.1	0.2	0.2	0.1	0.1	0.2

Source: Conway *et al*., 2005.

Contribution of the IPR regime

Data on IPR regimes were gathered by Ginarte and Park (1997) and updated by Park and Wagh (2002). They constructed an index of intellectual property rights, consisting of the following five underlying factors:

1. Coverage (the range of subjects that can be patented)
2. Duration (length of protection)
3. Enforcement (mechanisms for enforcing patent rights)
4. Membership in international patent treaties (for example the Paris Convention and Revisions)
5. Restrictions on patent rights (for instance compulsory licensing)

Table 6.2 Index of intellectual property rights, 2000

	Coverage	Duration	Enforcement	Membership	Restriction	Overall
EU15	0.82	1.0	0.93	1.0	0.52	4.28
US	1.0	1.0	1.0	1.0	1.0	5.0

Source: Park and Wagh, 2002.

Countries are assessed on each of these categories (ranging from 0 to 1). A score of 1 indicates that a country maintains the international standard period of protection (i.e. 20 years). Table 6.2 shows the estimated position of the EU15 and the US on these indicators.[110] The EU has a weak position on the sub-index *restrictions on patent rights* in particular. This sub-index measures to what extent patent holders are protected against the risk of forfeiting their patent rights. The

[110] The EU15 average comprises a weighted average (based on GDP) without the countries Finland, Greece, Luxembourg and Portugal.

index discriminates between three sources of protection loss: 1) 'working' requirements, 2) compulsory licensing and 3) revocation of patents.[111]

The overall position of the EU15 on the total index of IPR can be calculated for thirteen EU15 countries (including Finland and Portugal) and was extrapolated to cover the year 2001. Because changes in the IPR regime affect the R&D expenditure of business with a lag of one year, we can use the overall position of the EU in 2001 to calculate the contribution in 2002. In 2001, the overall position on the IPR index in the EU15 was 4.31, whereas the position of the US is at 5.0. Based on the calculations in Annex 1, we can conclude that the European IPR regime contributes 0.14 percentage points to the European R&D shortfall in 2002.

Conclusion
The position of the EU15 on inward-economic regulation and IPR explains a significant part of the European R&D shortfall compared to the US. We can tentatively conclude that fostering competition and deregulation in combination with a more rigorous IPR system could be an efficient strategy for the EU to narrow its R&D shortfall vis-à-vis the US. However, determining the most effective policy measures to realise a downscale of economic regulation and enhance the IPR system is a subject that needs more specific study.

6.3.8 Financial factors
A well-developed financial climate has a significant impact on the level of R&D activities conducted in the business sector. For example, the *profitability* of businesses is important for R&D investment decisions of businesses for two reasons. First, profits of firms are an important internal source of R&D financing (see, for instance, Himmelberg and Petersen, 1994). Second, the current profitability of a firm is a good indicator of future revenues that can be achieved with new investments, including R&D investments.

In addition, *the real interest rate* and the availability of *bank credits* are important indicators that represent the costs and possibilities of receiving external financing for R&D. The interest rate is negatively correlated with business R&D for two reasons. First, future revenues from R&D projects must be discounted for the current interest rate. Second, a higher interest rate decreases cash flows, thereby reducing the financial means to invest in R&D. The availability of *bank credits* is presumed to have a positive correlation with private R&D expenditure, as such credits generate funds for financing R&D. This variable is measured as the level of bank credits provided to the private sector, as a percentage of GDP.

The effect of the *business cycle* on the R&D intensity can be divided in two components. The business cycle generates a positive effect on private R&D, because relatively high profitability of businesses in high-growth periods leads to higher R&D investments. However, the business cycle also constitutes a negative effect, because R&D expenditures are long-term investments.

[111] See Ginarte and Park (1997, p. 287) for a further explanation of these three sources of protection loss.

As a consequence, the growth of R&D expenditure is not expected to keep pace with GDP growth during an economic boom. This has a negative effect on the R&D intensity. Because the positive effect of higher profitability on business R&D is already captured by the capital income quote (see below), we expect that the second (negative) effect prevails. The business cycle is therefore expected to have a negative relationship with business R&D.

Contribution of financial variables

Much research has been conducted on the influence of firm profitability on private R&D expenditure. Most of this research, however, consists of cross-sectional studies at the micro level (for a review of the existing literature, see Symeonidis, 1996; Hall, 2002). Donselaar and Segers (2006) examine the effect of profitability on private R&D expenditure at the macroeconomic level. Because no international comparable data are available on the profitability of businesses, however, the authors use the *capital income quote* as an indicator of profitability in their panel data estimates. The capital income quote is defined as the gross capital income as a percentage of business value added. Although the capital income quote covers more than profitability alone, it is still a useful indicator. The elasticity found by Donselaar and Segers (2006) is 0.14: if gross capital income as a percentage of value added of firms rises by 1%, private R&D expenditure as a percentage of GDP rises by 0.14%. Based on the calculations in Annex 1, we are able to derive that the lower capital income share in the EU15 (35.0% in 2002) relative to the US (36.5% in 2002) contributes only marginally (0.01 percentage points) to the R&D shortfall of the EU.

Guellec and Ioannidis (1997) find a semi-elasticity for the effect of the *real interest rate* on the private R&D intensity of -0.03, with a lag of three years. This means that an increase of one percentage point in the long-term real interest rate results in approximately 3% decrease in private R&D expenditure three years later. The calculations in Table A.1 of Annex 1 show that, in 2002, the lower real interest rate in the EU in 1999 (3.0%) relative to the US (4.2%) has a beneficial impact of 0.04 percentage points on the R&D position of the EU relative to the US.

Lederman and Maloney (2003), Bebczuk (2002) and Donselaar and Segers (2006) have conducted empirical research on the effect of the level of bank credits provided to the private sector (as a percentage of GDP) on the level of business R&D. Because of the arguments mentioned in the methodological explanation (Section 6.3.1), the elasticity of Donselaar and Segers (0.11) is used to quantify the contribution of the availability of bank credits on the R&D intensity. To the best of our knowledge, Donselaar and Segers (2006) are the only to have examined the impact of the business cycle on private R&D. The business cycle is measured by the deviation of gross domestic product from a five-yearly progressive average of GDP. They find an elasticity of -0.67. The calculation of the contribution of bank credits and the business cycle, respectively, can be derived from Table A.1 in Annex 1. The higher availability of bank credits in the EU has a positive effect of 0.07 percentage points on the R&D position of the EU relative to the US in 2002. In addition, the business cycle conveyed a marginal positive contribution of 0.01 percentage points.

6.3.9 Other factors

The list of determinants dealt with in the previous sections is by no means exhaustive. There are some conceivable determinants that also could have an important impact on the R&D position of countries, for instance the degree of protectionism, cultural aspects and human capital. There are two reasons why these factors were omitted from our analysis to disentangle the European R&D shortfall compared to the US:

(i) knowledge from the literature on the impact of certain drivers on private R&D is ambiguous;

(ii) data on drivers of private R&D in order to compare the European situation with that of the US in 2002 are not available.

To give an example, theoretically the amount of *human capital* in a country should have a major influence on a country's R&D expenditure.[112] After all, human capital is the main input for R&D processes. In the first place there is only few research done on this topic, which makes it hard to quantify the effect of human capital on private R&D. Secondly, the effects that are found are ambiguous or counterintuitive. For instance, Reinthaler and Wolff (2002) find a significant relationship between human capital and private R&D. However, if country dummies are included in the estimated specification (to control for unobserved heterogeneity), human capital no longer has a significant impact on private R&D. A similar problem applies to the work of Becker and Pain (2008). They find a significant positive effect of the number of scientists and technicians in R&D professions on private R&D expenditure. However, this variable relates to the amount of R&D personnel and thus represents a significant part of private R&D expenditure itself. Various other studies find little or no empirical evidence on the importance of human capital on private R&D expenditure (see, for instance, Bebczuk, 2002; Kanwar and Evanson, 2003).

A similar argumentation can be given for other possible relevant factors, like culture. Therefore, we conclude that more research is needed before making any valid statements about the effects of the factors that were omitted in this study.

6.4 OVERALL DECOMPOSITION

The US has outperformed the EU15 on the amount of private R&D expenditure as a percentage of GDP for a long time. Within the scope of European policy goals (Lisbon agenda and Barcelona target), this R&D gap should be narrowed significantly. In 2002, the R&D gap

[112] Human capital refers to the set of skills that an individual has acquired through education, training and experience, and which increase that individual's value in the marketplace.

between the EU15 and the US was 0.63 percentage points, based on OECD ANBERD data. The objective of this study is to provide more insight into factors that are responsible for the European shortfall in private R&D vis-à-vis the US.

The total shortfall of the EU15 can be divided into two main parts: a *sector composition effect* and an *intrinsic effect*. The sector composition effect between countries represents differences in the relative share of knowledge-intensive industries within the total economy. The contribution of the sector composition effect to the R&D gap between the EU15 and the US in 2002 was only 0.08 percentage point. The intrinsic effect is the complement of the sector composition effect and covers differences in the R&D intensity *within* sectors of the EU15 and the US. This intrinsic effect is responsible for the remainder (0.54 percentage points) of the private R&D gap. In the decomposition analysis performed in this study, the intrinsic effect is disentangled further into multiple components (see Table 6.3).

Table 6.3 Decomposition of R&D gap between EU15 average and the US (EU15-US), 2002, contributions in percentage points

Determinants	Contribution
Sector composition effect	***-0.08%***
Intrinsic effect	***-0.54%***
Foreign R&D investments	-0.11%*
Government funding of private R&D	-0.14%*
Fast-growing firms	-0.03%
Openness of the economy	+0.02%
Public R&D	
Higher education R&D	+0.01%
Public research institutions	-0.05%
Inward-oriented economic regulation	-0.30%**
Intellectual property rights	-0.14%
Capital income share (CIQ)	-0.01%
Real interest rate	+0.04%
Business cycle	+0.01%
Bank credits	+0.07%
Interaction effect	-0.01%
Residual	+0.10%
Total R&D shortfall	***-0.63%***

Commentary: * 2001, ** 2003.

The most important explanation behind the R&D gap is provided by institutional differences between the EU15 and the US. The higher level of *inward-oriented economic regulation* in the EU15 vis-à-vis the US accounts for roughly 0.30 percentage points of the total gap. This high contribution is caused mainly by differences on three low-level indicators that are part of *inward-oriented economic regulation*: the *scope of the public enterprise sector, direct control over business enterprise* and the *use of command & control regulation*. In addition, different institutional arrangements concerning intellectual property rights explain a significant part of the negative intrinsic position of the EU as well (i.e. 0.14 percentage points). Other important explanations are *government funding of private R&D* and *foreign R&D investments*, which account for 0.14 and 0.11 percentage points of the R&D gap, respectively.

Adding all of the partial contributions together reveals a total negative intrinsic effect of 0.64 percentage points; the effect is thus overestimated by 0.10 percentage points. There are numerous explanations for this overestimation. For example, a number of determinants (e.g. culture, human capital and outward R&D) have been omitted, largely because of data availability reasons and contradicting or lacking empirical evidence. These missing determinants could contribute positively to the European R&D position compared to the US, thereby counterbalancing the overestimated negative intrinsic effect. As previously noted, we lack the required information on some of these determinants to include them in this chapter. Secondly, because of the partial character of this study, omitted variable bias could also explain some of the slight overestimation of the intrinsic effect (see also Section 6.3.1).

Some remarks should be added on the dataset used for separating the intrinsic effect from the sector composition effect. Although these data are much more comparable between countries than in the past, there are still some measurement problems when comparing R&D intensities of sectors between countries. Especially the allocation of R&D conducted in the services sector causes some serious problems, which is already dealt with in Section 6.2. Therefore, future efforts into harmonisation of the data are recommended.

Despite these measurement problems, the analyses in the chapter indicate that, in contrast to conventional wisdom, the R&D gap between the EU and the US is not caused by a less R&D intensive economic structure of the EU relative to the US; a factor that is largely exogenous in the short term. Instead, a significant part of the gap seems to be policy-sensitive, as institutional factors (e.g. inward-oriented regulation, the IPR regime and government funding of R&D) play a major role in explaining the gap. Here lies a challenge for European policymakers – at both the national and European level – to create more favourable institutional conditions and to foster direct R&D stimulation in order to improve the European R&D performance.

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ANNEX 1. Contribution of variables with a multiplicative specification

Many variables have a multiplicative relationship with business R&D. The calculation of their contribution to R&D discrepancies between countries/regions is less straightforward than it is for determinants with an additive relationship (Sections 6.3.2 to 6.3.5). In this annex, we show how to conduct these calculations. Depending on the functional form, the estimated effect of a certain determinant must be transformed into a multiplicative specification. This transformation is different for logistic and semi-logistic specifications. Below, we show examples of these both types of specification.

Logarithmic specification

The relationship between the openness of the economy and business R&D has a logistic functional form. In 2002, the openness to foreign trade in the US was 23.6, and the weighted average openness of the EU15 was 24.9. By linking these data to the elasticity of 0.24, we can derive that the higher openness in the EU15 results in a positive effect on the R&D intensity of the EU15 compared to US of 1.0% ($\Rightarrow 100 \times ((24.9/23.6)^{0.24} - 1)$). This percentage can be used to compute a 'hypothetical R&D intensity' for the EU in 2002, assuming that the openness of the European economy is equal that of the US. The calculation is as follows: 1.23% (actual R&D intensity of the EU in 2002) $\times$ 1/(1+1.0/100) = 1.22%. The actual R&D intensity of 1.23% in 2002 minus the 'hypothetical' intensity of 1.22% reveals a positive contribution of the openness variable on the European R&D position compared to the US of 0.02 percentage points ($\Rightarrow$ 1.23% minus 1.22%, see also footnote 105).

Semi-logarithmic specification

Inward-oriented economic regulation and private R&D are related semi-logarithmically: one additional point on the index inward-oriented economic regulation (on a scale of 0 to 6) leads to a decrease in private R&D intensity by −0.27 to −0.36 percentage points (Bassanini and Ernst, 2007). By linking the semi-elasticity of −0.27 (we choose the lower level of this range) to the relative position of the EU15 (vis-à-vis the US, 2003) with regard to economic regulation of 0.8 (2.1 minus 1.3), the negative impact of economic regulation in 2003 on European R&D intensity can be fixed at 19.6% ($\Rightarrow 100 \times (e^{(0.8 \times -0.27)} - 1)$). This percentage can be used to compute a 'hypothetical R&D intensity' for the EU in 2002, which represents a situation in which the level of inward-oriented economic regulation in the EU is equal to that in the US. The hypothetical R&D intensity is: 1.23% (actual R&D intensity of the EU in 2002) $\times$ 1/(1+19.6/100) = 1.53%. The actual R&D intensity of 1.23% in 2002 minus the 'hypothetical' intensity reveals a negative contribution of the European position on inward-oriented economic regulation on the European R&D position compared to the US of 0.30 percentage points ($\Rightarrow$ 1.23% minus 1.53%).

Table A.1 Contribution of determinants with a multiplicative specification

	Method of calculations	Openness	HERD	GOVERD	Bank credits	Business cycle	Interest rate	Economic regulation	IPR	CIQ	Interaction effects	Sum of partial effects
Year of observation		**2002**	**2002**	**2002**	**2002**	**2002**	**1999**	**2003**	**2001**	**2002**		
Value EU15 average	A	24.9	0.42	0.24	1.05	0.98	3.0	2.1	4.31	35.0		
Value US	B	23.6	0.36	0.32	0.63	0.99	4.2	1.3	5	36.5		
Elasticity (semi-elasticity: *)	C	0.24	0.20^*	0.47^*	0.11	-0.67	-0.03^*	-0.27^*	0.72	0.14		
Position of the EU15 relative to the US	$D = A / B$ $D^* = A - B$	1.05	0.06	-0.08	1.68	0.99	-1.2	0.8	0.86	0.96		
Effect by linking position to elasticity	$E = D^c$ $E^* = e^{(D^* \times C)}$	1.01	1.01	0.96	1.06	1.01	1.04	0.80	0.90	0.99	0.78 [1)]	
Effect on EU15 R&D intensity due to its position on the determinant relative to the US (in percentages)	$F = 100 \times (E - 1)$ $F^* = 100 \times (E^* - 1)$	1.25	1.21	-3.67	5.88	0.64	3.54	-19.63	-10.11	-0.58	-21.76	
Hypothetical R&D intensity of the EU15, assuming the position on the determinant is equal to that of the US	$G = I \times 1 / (1 + F / 100)$ $G^* = I \times 1 / (1 + F^* / 100)$	1.22	1.22	1.28	1.16	1.22	1.19	1.53	1.37	1.24	1.58	
Partial effect (as a percentage of GDP)	$H = I - G$ $H^* = I - G^*$	0.02	0.01	-0.05	0.07	0.01	0.04	-0.30	-0.14	-0.01	-0.34	**-0.35** [2)]
R&D intensity EU in 2002	I	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	

Commentary: [1)] Equals the product of the ‘E’-values of all determinants, thus ($1.01 \times 1.01 \times 0.96 \times 1.06 \times \ldots$). [2)] Equals the sum of all partial effects: (0.02 + 0.01 + -0.05 + 0.07 + …).

Table A.1 presents an overview of the contribution of all variables in this study that have a multiplicative specification. In column 2 of Table A.1, the method of calculation is generalised by equations. The equations marked by an asterisk (*) correspond to semi-logarithmic relationships.

Interaction effects

When assessing the partial contribution of determinants that are estimated using a multiplicative functional form, it is important to consider the interaction effects between these determinants. The size of the interaction effects is examined by using a simple multiplicative interaction model, which is presented in Table A.1. The table shows the partial contributions of the determinants that have a multiplicative expression. To test whether significant interaction effects between these determinants occur, we first multiply all multiplicative effects.[113] Using the equations in the second column, this figure (0.78) can be transformed into a cumulative total contribution to the R&D gap of 0.34 percentage points. The size of the interaction effect can be derived by subtracting this cumulative figure from the sum of all separate partial effects. The sum of the partial effects equals 0.35 percentage points. We can conclude that there is a marginal interaction effect of 0.01 percentage points (see Table 6.3 in Section 6.4).

[113] These multiplicative effects are determined by linking the relative position of the EU to (semi-)elasticities.

ANNEX 2. Contribution of fast-growing businesses

In 2002, the private R&D intensity in the EU amounted to 1.23% of GDP. Because EIM data on fast-growing firms are only available for businesses in the size class 50 to 1,000 employees and our decomposition analysis covers the total economy, we need to know the share of total private R&D intensity that is accounted for by firms with 50 to 1,000 employees. Although this share is unknown for individual countries, Statistics Netherlands was able to calculate it for the Netherlands: 57%. In the OECD Science, Technology and Industry Scoreboard, the OECD also reports data on R&D shares for two other size classes, i.e. businesses with fewer than 50 employees and firms with 50 to 249 employees. Combining these two data sources, we are able to estimate the required shares for the other eight European countries and the US (see below).

As previously stated, firms with 50 to 1,000 employees conduct 57% of total private R&D in the Netherlands. Data from the OECD show that 9.3% of total R&D in the Netherlands is performed by firms with fewer than 50 employees, and 18.3% is executed by firms with 50 to 249 employees. Combining these data shows that 38.7% of R&D is performed by firms with 250 to 1,000 employees, and 33.7% is conducted by firms with more than 1,000 employees. OECD data are also available for the other eight EU countries and the US, for the size classes <50 and 50-249. For all of these countries, the ratio of R&D expenditure by firms with 250 to 1,000 employees relative to the R&D expenditure by firms with more than 1,000 employees is assumed to be equal to the ratio in the Netherlands (1.15 = 38.7%, divided by 33.7%). Under this assumption, the share of total R&D expenditures for firms with 250 to 1,000 employees can be calculated for each country. The share of total R&D expenditure accounted for by firms with 50 to 249 employees was obtained from OECD data. This share was added to the computed share of firms with 250 to 1,000 employees to obtain the share of total R&D expenditures accounted for by firms with 50 to 1,000 employees.

In the EU, 55.7% of R&D is conducted by firms with 50 to 1,000 employees. It is assumed that these shares were the same for both 2002 and 2001. The total R&D expenditure in the EU in 2002 amounts to € 104.5 billion. Hence, € 58.2 billion ($\Rightarrow$ € 104.5 billion $\times$ 0.557) is invested by firms with 50 to 1,000 employees. Finally, data on the number of firms with 50 to 1,000 employees are required for both the EU and the US. These data (for 2003), which were kindly made available by Pauline de Jong of the EIM, originate from Eurostat and US Census Bureau.

The number of firms in the EU (i.e. the nine EU countries for which data are available) with 50 to 1,000 employees is 149,320. Approximately 13.9% (20,705) of these firms are fast growers; hence 128,615 are non-fast-growers. Because fast-growing businesses invest 40% more in R&D than non-fast growers do, the total number of businesses must be transformed into R&D 'equivalents': (20,705 $\times$ 1.4) + (128,615 $\times$ 1) = 157,602. The average R&D expenditure for each R&D equivalent in the size class 50-1000 employees amounts to € 369,200 ($\Rightarrow$ € 58.2 billion divided by 157,602).

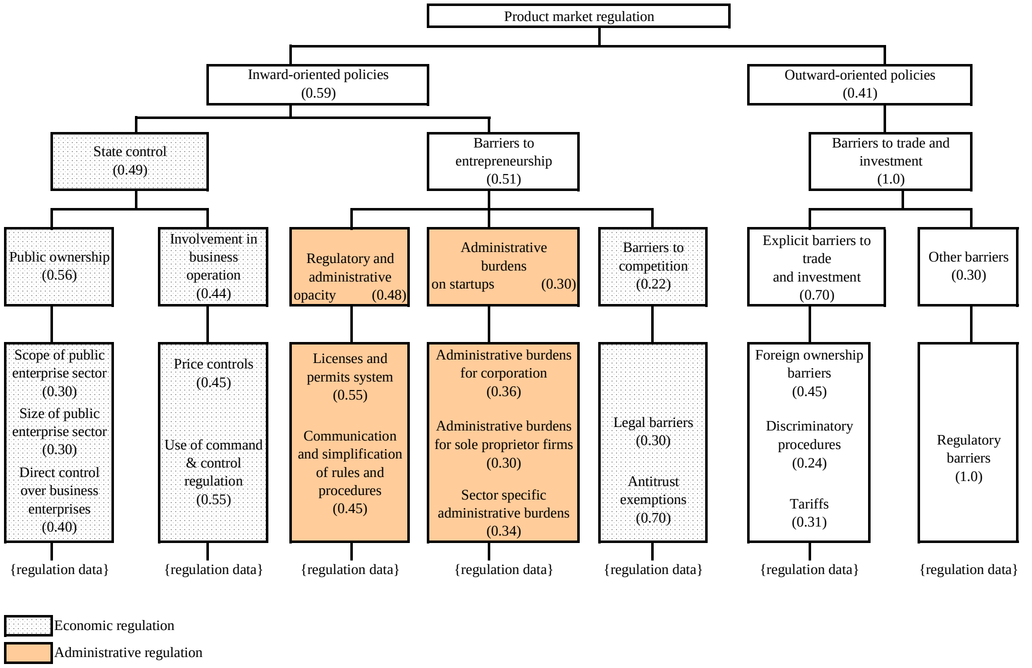
Table A.2 Contribution of fast-growing firms to the R&D gap

	Method	EU versus US
Current situation in the EU:		
R&D intensity in 2002, % of GDP	A	1.23
Share of firms with 50-1,000 employees in total private R&D	B	0.557
Private R&D expenditures of firms with 50-1,000 employees, % of GDP	C = A × B	0.68
GDP in 2002	D	€ 8,495,423,410,115
R&D expenditure in 2002	E = A / 100 × D	€ 104,493,707,944
R&D expenditure in 2002 of firms with 50 to 1,000 employees	F = B × E	€ 58,186,708,265
R&D expenditure of firms in other size classes	G	€ 46,306,999,679
Share of fast-growing firms (50-1,000 empl.), EU (2000-2003)	H	0.139
Share of fast-growing firms (50-1,000 empl.), US (2000-2003)	I	0.235
Difference between US and EU	J = I – H	0.096
Number of firms with 50 to 1,000 employees	K	149,320
Number of fast-growing firms (50-1,000 employees)	L = K × H	20,705
Number of non-fast-growing firms (50-1,000 employees)	M = K – L	128,615
Fast-growing firms spend 40% more on R&D	N	1.4
Number of firms (50-1,000) expressed in 'R&D-equivalents'	O = L × N + M	€ 157,602
R&D expenditure (50-1,000) per 'R&D-equivalent'	P = F / O	€ 369,200
Situation if share of fast-growing firms in the EU is equal to the US:		
Number of fast-growing firms (50-1,000 employees)	Q = K × I	35,090
Number of non-fast-growing firms (50-1,000 employees)	R = K – Q	114,230
Private R&D of fast-growing firms (50-1,000 employees)	S = Q × P × N	€ 18,137,431,441
Private R&D of non-fast-growing firms (50-1,000 employees)	T = R × P	€ 42,173,662,773
Private R&D of firms with 50-1,000 employees	U = S + T	€ 60,311,094,214
Total private R&D expenditure	V = U + G	€ 106,618,093,894
Total private R&D expenditure, % of GDP	W = V / D × 100	1.26
Difference between hypothetical and current situation	X = W – A	0.03

Source: Eurostat; US Bureau of the Census; OECD Main Science and Technology Indicators, 2006-2.

If we hypothesize that the share of fast-growing firms in the EU is equal to the share in the US, implying an increase from 13.9% to 23.5%, the number of fast-growing firms in the EU would amount to 35,090 (149,320 × 0.235) instead of 20,705. The number of non-fast-growing-firms would decline to 114,230. The total R&D expenditure of all firms with 50 to 1,000 employees would be € 60.3 billion ($\Rightarrow$ (35,090 $\times$ 1.4) $\times$ 369,200 + 114,230 $\times$ 369,200). The R&D expenditure of the firms in other size classes (i.e. fewer than 50 employees and more than 1,000 employees) would be € 46.3 billion ($\Rightarrow$ (1 − 0.557) $\times$ € 104.5 billion). In summary, the total R&D expenditure in the EU would be € 106.6 billion instead of € 104.5 billion. This means that the R&D intensity of the EU would be 1.26% instead of 1.23%. In Table A.2, all calculations are put together (with the corresponding equations in the second column). These results show that the R&D intensity of the EU would be 0.03 (1.26% minus 1.23%) percentage points higher if the share of fast-growing companies in the EU would be equal to the share in the US.

ANNEX 3. The PMR index system



Note: Weights were derived from a principal components analysis performed separately on regulatory data entering each of the main domains of regulation (state control, barriers to entrepreneurship, barriers to trade and investment, economic regulation and adminsitrative regulation). A similar principal components analysis was also performed on the domains entering the indicator of inward-oriented policies (state control and barriers to entrepreneurship), and the summary indicator of regulation (inward- and outward-oriented regulations).
The principal components analysis was based on the original 1998 data.

Source: Conway *et al.* (2005).

In: *Economics of Innovation and New Technology*, forthcoming

CHAPTER 7

Location factors of international R&D activities: A multi-level perspective

7.1 INTRODUCTION

The internationalisation of business research & development (R&D) accelerated during the second half of the nineties making it a topic of growing interest to the business community, academics and policymakers. Many countries attempt to increase their investments in R&D, because this is one of the channels through which the knowledge-based economy can be strengthened. Particularly the attraction of foreign R&D investments is becoming increasingly important, as foreign R&D constitutes a growing proportion of total R&D investments. The main question in this chapter is: 'How can a country attract high levels of foreign R&D investments?' In order to answer this question, one needs to know which location factors are decisive for a country's attractiveness to foreign R&D. Note that the sword cuts both ways here: the location factors that are important for attracting foreign R&D investments will be similar to those that are important for preventing home-based businesses from relocating their R&D to other countries. This implies that it is even more important for national governments to ensure that their country is able to offer an excellent R&D investment climate.

In this chapter we attempt to quantify the importance of the relevant R&D location factors. We adopt a *multi-level perspective* to examine the location determinants of R&D investments. Besides a literature review, we performed a field study among 62 research subsidiaries situated in eight countries as well as six in-depth interviews with foreign multinational organisations (MNOs) operating in the Netherlands. In addition, we conducted an econometric analysis using macro- and industry-level panel data from the OECD on inward R&D investments and foreign-owned patents. The analysis from a multi-level perspective enables us to generalise the results and quantify the effects more easily without losing awareness of the underlying complexity of R&D flows. Most other empirical studies are based on a sample of at most 300 MNOs originating from a small number of countries (cf. Hakånson and Nobel, 1993; Florida, 1997; Medcof, 1997; Fors, 1998; Kuemmerle, 1997, 1999; Patel and Vega, 1999; Pearce, 1999; Kumar, 2001; Le Bas and Patel, 2007). One could question whether the results from these survey studies are applicable to other countries on a higher level of aggregation. In this chapter, therefore, we follow Doh *et al.* (2005), Jones and Teegen (2003) and Papanastassiou (1997a, 1997b) by utilising aggregated data to identify the importance of various location factors of R&D.

As far as we know, this chapter is the first attempt to construct a robust set of relevant R&D location factors by using a multi-level perspective. The results of this chapter are valuable for policymakers who are occupied with attracting foreign direct investments (FDI) in R&D on the one hand, and on the other hand to policymakers who are concerned about the offshoring of R&D activities to other countries. The identified R&D location factors provide a policy framework for both categories of policymakers.

The structure of this chapter is as follows. Section 7.2 deals with the economic background of foreign R&D investments. An answer is given to the question why it is important, from an economic perspective, to focus on foreign R&D investments and the underlying location factors. We discuss the importance of the location factors of R&D in the two subsequent sections. In Section 7.3 we have a closer look at the location factors of R&D based on existing insights from the literature and the results from a field survey. Section 7.4 separately discusses the findings from an econometric analysis. Section 7.5 summarises and concludes the chapter and provides some policy options.

7.2 ECONOMIC BACKGROUND

The Europe of today is faced with an ageing population, which restricts the possibilities for extensive factor-driven growth. To ensure future economic growth, many countries will have to rely on labour productivity growth to a much larger extent. In consequence, politicians, policymakers and academics are interested in the various determinants of productivity growth. Innovation is considered to be one of the most important drivers of productivity growth (cf. Baumol, 2002; Jones, 2002).

R&D is the most practical indicator for innovation.[114] As a result, most empirical studies use the R&D capital approach to explain productivity growth. This approach implies that the development of the supply of R&D capital is related to the development of total factor productivity (see Chapters 3 and 9 of this dissertation).[115] In the long run, one additional euro spent on R&D leads to a multiple of this amount in terms of value added. This multiplier seems

[114] A higher level of R&D expenditure does not necessarily lead to a higher amount of innovations. R&D is one of the input factors in the total innovation process and disregards the output side (see, for instance, Acs and Audretsch, 2005; Klomp, 2001). After all, many other factors play a role of significance and a soundly working innovation system is needed to actually achieve a high output from R&D activities (OECD, 2002). The reason for using data on R&D investments as an indicator is simple: internationally comparable long time series on innovations are not available.

[115] For an explanation of the R&D capital approach see, for instance, Griliches (2000) and Annex 1 of this chapter.

to be at least 5, but could possibly be higher than 10 (Coe and Helpman, 1995, 2008; OECD, 2000; Guellec and Van Pottelsberghe de la Potterie, 2004; Bassanini *et al.*, 2001; Jacobs *et al.*, 2002). Furthermore, countries with a relatively low level of technological development can benefit from knowledge that is developed elsewhere by using it in their own products or production processes. Through catching-up, these countries can narrow the gap in productivity with the technological leader. A country's own R&D capacity and stock of human capital contribute positively to the speed of this catching-up process (Griffith *et al.*, 2004). Verspagen (2001) argues that a country needs a higher R&D intensity of its own in order to absorb newly developed knowledge.

Table 7.1 Contribution of foreign R&D investments to domestic private R&D intensity, contribution in percentage points, averages over 1995-2004

	Private R&D/GDP(%)	Inward R&D/ GDP (%)	Inward R&D/private R&D (%)
Ireland	0.84	0.56	66.8
Sweden	2.81	1.04	36.1
Czech Republic	0.71	0.26	35.5
UK	1.23	0.42	35.2
Canada	1.10	0.34	31.2
Spain	0.48	0.14	30.1
Italy	0.53	0.15	28.2
Portugal	0.27	0.06	26.2
The Netherlands	1.06	0.30	25.0
France	1.40	0.27	19.4
Germany	1.63	0.31	18.8
Finland	2.10	0.31	14.0
US	2.00	0.25	13.3
Poland	0.22	0.02	10.7
Japan	2.30	0.07	2.9
EU15	**1.18**	**0.31***	**24.4***
OECD	**1.55**	**0.24****	**14.7****

Source: calculations of the Dutch Ministry of Economic Affairs, based on OECD AFA database, OECD Economic Outlook (no. 82) and OECD Main Science and Technology Indicators. * Weighted average for: Finland, France, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden and the UK. ** Weighted average for: Canada, the Czech Republic, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Poland, Portugal, Spain, Sweden, the UK and the US.

European political leaders recognised the necessity to increase productivity growth, and the role of innovation and R&D in realising that growth, by formulating two ambitious policy objectives. First of all, *the Lisbon agenda* states that Europe must transform into the most competitive region in the world by 2010 (European Commission, 2002). Secondly, *the*

Barcelona target aims to raise R&D in Europe towards 3% of GDP and that two-thirds of this new investment should come from the private sector (European Council, 2002). Whether or not these goals are realistic is of less importance; the main message is that productivity growth must accelerate in Europe and innovation is key for this. The necessity of innovation for future productivity growth (and consequently economic growth), the high (European) ambitions and the increasing competitiveness to enhance the innovative climate are rationales for national governments to study the underlying investments in R&D. Foreign R&D investments constitute a relatively large part of total private R&D investments (see Table 7.1). In Ireland, foreign firms contribute almost 67% to the total private R&D expenditure, and in many other countries it ranges between 25%-35%. At the other end of the spectrum, foreign firms conduct only 3% of all business R&D in Japan. Overall, foreign R&D investments contribute quite heavily to private R&D intensity and over time this contribution has increased profoundly in certain countries as well (e.g. the US, the UK, Germany and Finland).

Besides the significant *direct* contribution of foreign R&D investments to the total business R&D, foreign R&D investments also have two *indirect* benefits for countries. First of all, these investments function as a transmission channel for international knowledge spillovers (see, for instance, Keller and Yeapl, 2003). In other words, foreign knowledge-intensive businesses can fulfil a bridging function between a country's own innovation system and knowledge developed abroad. Part of the technology within the foreign affiliate located in a certain country flows to local suppliers in that country, local personnel employed by the affiliate, and local knowledge institutions co-operating with the foreign technological affiliate. There are indications that the local knowledge spillover effects from foreign R&D activities in a country are equal to the spillover effects from R&D activities conducted by native firms (see, for instance, Jaffe *et al.*, 1993). Secondly, foreign R&D could boost competition within a country and thus force resident firms to reduce their x-inefficiencies and increase innovative activities.[116] Besides the reduction of x-inefficiencies, the location of R&D within the most important and dynamic markets, which are characterised by a high level of competition, will lead to higher learning capacities for these businesses. Surely, a competitive market increases the capacity of a business to learn from their competitors and absorb knowledge spillovers to a larger extent (Porter and Sölvell, 1998). As a consequence, this enables companies to innovate at a higher level.

The position with regard to inward R&D depends on the quality of the R&D investment climate. This means that the attractiveness of a country for R&D investments from abroad is determined by its performance on a number of location factors. A high performance on these location factors works two ways: attracting new foreign investments and preventing home-based businesses from relocating R&D abroad. In the next two sections, we will examine these R&D location factors. Section 7.3 presents an overview of the literature on R&D location factors and

[116] X-inefficiencies are various forms of inefficiency caused by poor communication, ignorance or neglect by suppliers, buyers, managers or employees (Leibenstein, 1966).

in Section 7.4 an econometric analysis is conducted which enables us to quantify the impact of several location factors on multinationals' R&D investments.

7.3 LOCATION FACTORS OF R&D: LITERATURE AND FIELD RESEARCH

7.3.1 Literature review

The geographical location of R&D investments is determined by considerations both internal and external to the firm. The internal ones regard firms' motives underlying the observed internationalisation of R&D investments. External considerations, in contrast, encompass the factors determining a location's R&D investment climate. Of course, this distinction leaves aside several interactions. Internal and external considerations (motives and location factors) are highly interrelated. Making this coarse distinction does, however, provide a useful framework for this chapters' survey of factors determining the location of foreign direct R&D investments.

Motives behind R&D internationalisation (internal considerations)

In the literature a wide array of motives (internal considerations) for firms to invest in R&D abroad are discerned.[117] Vernon (1966) provides a seminal contribution to the study of location patterns of economic activities. Vernon observed that many of the products newly introduced in the twentieth century have their origin in the United States (e.g. semiconductors, (personal) computers, etc.). The reason underlying this observation is, according to Vernon, the fact that the US provides a large market for new products due to its large population, the high per capita income and the assumption that domestic (US) producers have superior understanding of the local market. The product's conception is the starting point for the product's life cycle in which demand first takes off, stabilises as the product matures and ultimately declines. Vernon tied this product life cycle concept to the location of production and the (resulting) patterns of trade. Over time, as a product matures, production moves from its location of origin (i.e. the United States) to other places and patterns of trade change correspondingly. As this process continues, a geographical life cycle emerges. At first, all production takes place in the US and the US serves any overseas demand through exports. In the next phase, production starts in places outside the US, e.g. in Europe. The relevance for the location of R&D (and especially the development part) is that in these overseas factories generally some adjustments to products are made to better suit the local market. In short, the product life cycle theory asserts that the innovative core competences of a business are located at the home base. R&D facilities abroad are merely set up for the purpose of adapting centrally created products and processes to meet local market circumstances.

Another notable attempt to map the drivers of outward R&D investment is posed by Ronstadt (1978). He observed the emergence of international R&D units that conducted tasks that reached beyond mere adaptation of centrally developed products and processes. Certain R&D

[117] See Niosi (1999) for an overview.

units developed new products and processes for the global market as well (which he refers to as *global technology units*) or even fundamental research to foster the long-term competitiveness of the whole company (so-called *corporate technology units*). The development of both types of R&D units clearly do match with the product life cycle model, as their R&D activities are complementary to those undertaken at the home base in order to increase the knowledge base of the whole company. The underlying idea is that a firm is able to benefit from local knowledge spillovers by locating its R&D facilities near areas where state-of-the-art expertise is situated (we return to this element in more detail when discussing the location factors c.q. external considerations). Physical presence enables the transition of ‘tacit knowledge’ and the opportunity to penetrate local knowledge networks at low costs. Goedegebuure (2000), for instance, shows that it is important for R&D personnel to build a local network with suppliers and knowledge institutions.[118]

Several authors continued to extend the analyses of Vernon (1966) and Ronstadt (1978) (see, for example, Bartlett and Ghoshal, 1990; Howells, 1990; Hakånson and Nobel, 1993; Niosi, 1999; Kuemmerle, 1997, 1999; Von Zedwitz and Gassmann, 2002). Patel and Vega (1999) and Le Bas and Sierra (2002) argue that there are two dominant firm motives or strategies related to the location of technological activity (also see Kuemmerle, 1997 and 1999; OECD, 1998):[119]

1. *Home-base exploiting strategy (HBE)*: the purpose of these R&D investments is to exploit the existing corporate-specific capabilities in foreign environments (see, e.g. Le Bas and Patel, 2007). Kuemmerle (1999) observes that in case of an internationalisation strategy aimed at exploiting home-base advantages and capabilities (HBE), R&D units were established in the vicinity of manufacturing and marketing facilities. The idea is that these subsidiaries are launched abroad with the purpose of adapting centrally created products and processes to meet local market circumstances (see, for instance, Fors 1998). Often, the *HBE* strategy is referred to as *‘product adaptive R&D’*, since R&D subsidiaries are used to adapt parent technology to the host country market (Le Bas and Patel, 2007). In this sense, the HBE motive of international R&D relates to the product life cycle theory of Vernon.
2. *Home-base augmenting strategy (HBA)*: within this strategy, R&D activities are developed at locations where there is an obvious strength in a certain area of technology in which the investing firm also has a relative advantage at the home base. This motive closely matches the ‘new’ R&D patterns identified by Ronstadt (i.e. global technology units and corporate technology units). New local R&D activities are complementary to the central R&D activities and focus on expanding the firm’s knowledge base. R&D units established with

[118] Most of the time a business will use small-scale listening posts in order to capitalise on local state-of-the-art expertise (see, for instance, Fors, 1998; Pearce, 1999; Gassmann and Von Zedtwitz, 1999; Patel and Vega, 1999). In some cases, these local listening posts mature into full-scale centres of excellence (Von Zedtwitz and Gassmann, 2002).

[119] Patel and Vega (1999) and Le Bas and Sierra (2002) also mention two other firm strategies with regard to foreign direct investments (FDI) in R&D. First, *‘host country-exploiting FDI’* as a strategy focuses on exploiting a country’s technological advantages in areas of domestic weaknesses. Second, market-seeking FDI as a strategy is often not technology-driven. Moreover, it involves mergers and acquisitions, where the possession of technological assets is a by-product rather than the initial motivation (Le Bas and Patel, 2007).

the aim of augmenting the knowledge base of a business (HBA) are generally located nearby universities and other knowledge institutes (Kuemmerle, 1999). Von Zedtwitz and Gassmann (2002) refer to the *HBA strategy* as the *'access to science strategy'*.

The corporate internationalisation and diversification of technological activity are two ways of spreading the competence base of the firm and of acquiring new technological assets or sources of competitive advantage (Cantwell and Piscitello, 2002). Interestingly, there appears to be an evolutionary pattern regarding both motives (HBE and HBA). Although the *HBE strategy* or the *adaptive R&D strategy* still seems to be the dominant driver behind the internationalisation of R&D (see, for instance, Hakånson and Nobel, 1993; Fors, 1998; Ambos, 2005), foreign R&D subsidiaries are increasingly established to gain access to (complementary) state-of-the-art knowledge and skills (cf. Pearce, 1999; Le Bas and Sierra, 2002; Roberts, 2001; UNCTAD, 2005). In consequence, locations for R&D are nowadays more and more driven by scientific supply side motives as opposed to market-driven purposes and, hence, the *HBA strategy* or *access to science strategy* seems to win ground as the dominant strategy for foreign direct investments in R&D (see, for instance, Cantwell and Piscitello, 2005; Florida, 1997; Serapio and Dalton, 1999). This brings us to the external considerations to firms, i.e. the location factors of R&D investments; or put differently: 'What determines *where* MNOs locate R&D in the developing world?'

Location factors of R&D (external considerations)
Several studies examined the location factors of R&D activities from an empirical point of view. Table 7.2 summarises the most important outcomes of some of these studies. An important location factor underlying the HBE strategy or adaptive R&D strategy is the *value added of foreign affiliates*, as this type of R&D is closely related to production (see Hakånson and Nobel, 1993; Kuemmerle, 1999). Secondly, the *size of markets* is an important factor: the larger the host market, the greater the need for local adaptation of goods and services. GDP or GDP per capita is often used to reflect the attractiveness of the host market for conducting business, including R&D activities (see Doh *et al.*, 2005).

A location factor that seems to be of crucial importance to both home-base exploiting FDI in R&D as well as home-base augmenting FDI in R&D is the *availability of highly skilled human resources*, especially scientific and technical manpower (see Florida, 1997; Kumar, 2001; Jones and Teegen, 2003; UNCTAD, 2005; Thursby and Thursby, 2006; Papanastassiou, 1997a; Balasubramanyan and Balasubramanyan, 2000). UNCTAD (2005, p. 161) concludes: *"As national markets become regionally more integrated, some countries may become the preferred base for adaptation, not only for the local market but for the region as a whole. In this case, appropriate skills and other aspects of the national innovation system (such as the technical and economic infrastructure, proximity to suppliers/key customers) become more important. Depending on the industry, adaptive R&D needs technical and engineering skills that are specialized in the technologies used in production."*

Table 7.2 Empirical studies on R&D location factors

Study	Research methodology	Most important location factors of R&D
Hakånson and Nobel (1993)	Survey among 20 Swedish MNOs in 1987 covering 170 foreign affiliates.	Political factors and the closeness to markets explain respectively 34% and 32% of foreign affiliates' R&D employment. Only 8% of the R&D employment is explained by incentives to tap into the foreign knowledge base.
Florida (1997)[120]	Survey among 207 foreign-owned stand-alone R&D establishments in the US.	The R&D expenditure of foreign affiliates significantly relates to three factors: (1) the access to scientific and technological information, (2) access to highly skilled scientific and technological human talent and (3) the connection to the scientific and technical community.
Fors (1998)	Data in 1978 and 1990 with regard to 100 Swedish MNOs.	Location factors relating to adaptive R&D processes are found to be dominant in explaining R&D expenditure by Swedish foreign R&D affiliates, i.e. the share of value added of Swedish MNOs in industry *x* of country *y*. The study also shows that access to state-of-the art knowledge is becoming increasingly important: firms concentrate a larger share of their R&D in countries that are characterised by a high rate of technological specialisation.
Kumar (2001)	Data on 74 US and Japanese MNOs for the years 1982, 1989 and 1994.	A large domestic market, the abundance of low cost R&D manpower, and the scale of national technological effort favour the location of overseas R&D in a country.
Cantwell and Piscitello (2002)	Patent data covering the period 1969-1995 with regard to the countries Germany, the UK, France and Italy.	The relative attractiveness of regions in Europe to the technological efforts of foreign-owned MNOs (measured by the number of applied patents to foreign affiliates) depends on: (1) the presence of external sources of knowledge, (2) the presence of industry-specific and cluster-based spillovers and (3) the breadth of local technological specialisation in the region, i.e. the opportunity to capture general purpose spillovers.
Doh, Jones, Mudambi and Teegen (2005)	Data from US government benchmark survey, measuring the foreign activities of US MNOs.	The quality of the local innovation system is an important location factor in explaining foreign R&D activities by US MNOs. The results indicate that almost 70% of the observed variation in foreign R&D intensity (inward R&D as a percentage of GDP) can be explained by (1) economic variables (total GDP and GDP per capita) and (2) scientific output (the average number of scientific articles published annually).
Thursby and Thursby (2006)	Survey over 200 MNOs from 15 different countries in 2005.	For developed economies, the quality of R&D personnel and IP protection are ranked as the most important decision factors for multinational R&D localisation. Also important are the expertise of university faculty and the ease of collaborating with universities. In developing economies, the potential local market size and the quality of R&D personnel take precedence.
Jones and Teegen (2003)	Aggregated data from the US Department of Commerce concerning the R&D investments of US MNOs abroad in 1994.	Firms locate foreign R&D capabilities in the primary markets for the products produced by their overseas affiliate. They attach great value to the availability of highly educated graduates in science and engineering for staffing their overseas operations.

[120] A drawback of this study is that only 'stand-alone' establishments were included in the survey. These units are more likely to follow a home-base augmenting strategy. The results from the survey would have been more convincing if 'incorporated' R&D units were examined as well. Incorporated R&D units are physically linked to other business activities (for instance production, logistics and headquarters) and relate to the home-base exploiting motive behind FDI in R&D (see Buck Consultants International, 2004).

Another important aspect in the location decision of firms is the possibility to benefit from *knowledge spillover effects*. The general idea is that geographic concentration of innovative activity generates knowledge spillovers as one firm's activities aid the advancement of other technologically similar firms (see, for instance, Audretsch and Feldman, 1996; Baptista and Swann, 1998). In other words, R&D firms can take advantage of their competitors due to the spillover effects of research. Proximity to competitors is needed to capitalise on these spillover effects. Indeed, high-quality clusters bring about agglomeration effects and function as a magnet to attract knowledge intensive (foreign) firms (see, for instance, Cantwell and Piscitello, 2002).The idea is that within these agglomerations, there is a higher probability that firms can penetrate (tacit and codified) knowledge relevant to them more efficiently and at lower costs than producing this knowledge internally or trying to acquire it from a geographical distance (see Harhoff, 2000).

Closely related to the importance of highly innovative clusters as a location factor are possibilities for firms to co-operate with third parties. Firms can decide to form alliances with competitors or collaborate with universities in certain research projects. For instance, empirical research by Karlsson and Andersson (2005) shows that there is a strong path-dependence in the location of both industrial and university R&D. Concerning this interdependence, especially the location of industrial R&D seems to be quite sensitive to the location of university R&D.

The significance of *labour costs of R&D personnel* for the acquisition of R&D investments from abroad is ambiguous in the literature. Some studies, for instance Kumar (2001), The Economist (2004) and Buck Consultants International (2004), find a significant influence of labour costs of R&D personnel. Other studies conclude that cost elements (e.g. R&D labour costs) are less important than quality aspects of the investment climate (see, for instance, Cornet and Rensman, 2001; Edler *et al.*, 2001; Jones and Teegen, 2003).

A number of *framework conditions* may increase the attractiveness of a country for locating R&D activities, but the literature pays less attention to these factors. Some of these framework conditions are flexible licensing procedures, a well-functioning IPR regime (IPR stands for intellectual property rights), national security, a sound physical infrastructure, or the availability of natural resources (sea water, clean air, fossil fuels), access to sufficient financial means and the existence of suppliers of high-quality materials (see Brockhoff, 1998).[121]

We complete this section by identifying some location factors that are directly related to government intervention, although the number of discussed R&D location factors in this section is not limitative. The government has a role in maintaining and expanding existing R&D as well

[121] Empirical evidence on the importance of IPR regimes is contradicting. Kumar (2001) concludes that patent protection (as well as restrictive trade regimes) does not affect the attractiveness of a country for foreign R&D investments. However, Thursby and Thursby (2006) do find evidence that intellectual property protection is an important location factor for multinational R&D activities.

as acquiring R&D from abroad. For instance, governmental foreign investment agencies fulfil an important role in keeping close contact with foreign firms, building networks of trust and persuading these firms to invest in their country. Other important location factors are the provision of an attractive corporate tax regime, political stability, stability on the labour market, R&D stimulation incentives (e.g. R&D subsidies and R&D tax credits) and creating sufficient market opportunities (either by fostering competition or by fulfilling the role of launching customer).

7.3.2 Field research

To test the validity of the identified location factors from the literature, field research was conducted among 62 foreign companies with international R&D establishments (see Buck Consultants International, 2004). This study was commissioned by the Dutch Ministry of Economic Affairs. Among the 62 surveyed R&D subsidiaries, 30 are located in the Netherlands, 7 in France, 7 in Ireland, 5 in the UK, 4 in Belgium, 4 in Germany, 3 in Sweden and 2 in Switzerland. Although the sample used in our field research is hardly representative for Europe as a whole, it does have a benefit over most other surveys that restrict their sample to one country. The 30 foreign R&D affiliates in the Netherlands were selected from a database containing all known foreign R&D affiliates operating in the Netherlands (which are 72 affiliates). To make a representative selection, several characteristics of the affiliates were taken into account, e.g. industry, type of affiliate, region, and the country of origin. Of all interviewed affiliates (in the Netherlands as well as outside the Netherlands), 68% are stand-alone establishments, meaning that they operate physically independent from other business activities (logistics, sales, production, etc.). The remaining 32% of the examined affiliates are incorporated R&D units. For more details on the characteristics of the sample we refer to the report by Buck Consultants International (2004).

Based on the literature review, we identified 19 important location factors for international R&D investments. The foreign R&D subsidiaries were asked to qualify the importance of these location factors by indicating whether a location determinant was crucial, important, reasonably important or unimportant to them. Table 7.3 shows the results of the survey. For all location factors, two indicators have been calculated. First, the percentage of companies that considered this factor to be either crucial or important in their location decision, and secondly, a weighted average that also takes the answer ‘reasonably important’ into account and utilises the different values of ‘crucial’ versus ‘important’ versus ‘reasonably important’. Both indicators are presented in the last two columns.

The results presented in Table 7.3 clearly indicate that the *availability of highly skilled personnel* is the most important location determinant for R&D. This location aspect is considered crucial by 22 of the 62 respondents and crucial or important by more than 90% of the respondents. The top three location factors are complemented by *international accessibility* and the *quality of the knowledge infrastructure/universities*. The difference between the companies situated in the Netherlands and those located in other countries were very small and will therefore not be discussed in this chapter. The interested reader is referred to Buck Consultants International (2004).

In short, our field research shows that businesses locate their R&D in the proximity of highly qualified people, who are easy to access and who have access to state-of-the-art knowledge. In addition, we note that while financial factors such as *R&D stimulation incentives*, the *labour costs of R&D personnel* and *tax regulations* are important, they are not decisive in order to attract foreign R&D.

Table 7.3 Importance of location factors of R&D, survey results

Rank	Location factors	Crucial	Important	Reasonably important	Percentage crucial or important	Alternative score
1	Availability of highly skilled personnel	22	35	4	91.9%	0.65
2	International accessibility	11	37	11	77.4%	0.52
3	Quality of the knowledge infrastructure/universities	14	24	20	61.3%	0.50
4	Co-operation between firms and knowledge institutions	10	25	20	56.5%	0.44
5	Capacity and quality of ICT infrastructure	9	25	19	54.8%	0.42
6	Costs of R&D personnel	5	29	21	54.8%	0.40
7	Quality of life	5	27	22	51.6%	0.39
8	R&D stimulation incentives	10	20	21	48.4%	0.41
9	Tax regulations	6	24	18	48.4%	0.36
10	Entrepreneurial climate which fosters innovation	5	25	17	48.4%	0.35
11	Proximity to lead users and/or strategic partners	15	13	17	45.2%	0.42
12	Regulation and legislation	7	21	20	45.2%	0.36
13	Presence of high-quality clusters/industries	5	19	20	38.7%	0.31
14	Costs of business accommodation	4	19	30	37.1%	0.34
15	Relation with other activities current location	8	14	18	35.5%	0.31
16	Location in relation to other establishments	4	14	28	29.0%	0.29
17	Technology and science parks	4	12	27	25.8%	0.27
18	Access to venture capital	3	10	15	21.0%	0.19
19	Government functioning as launching customer	2	6	15	12.9%	0.14

Source: calculations by the Ministry of Economic Affairs based on Buck Consultants International (2004). Explanation: the alternative score is calculated by weighing the sum of the scores ‘crucial’, ‘important’ and ‘reasonably important’. The relative weights are 1, ½ and ¼. The sum of the scores is subsequently divided by the total number of observations (62).

Independent of the choice of indicator, the first twelve location factors are more important than the other factors. Apart from some other location factors which apparently are of lower importance, especially the *access to venture capital* and the *government as launching customer* seem to have very little relevance to firms in their location decisions for R&D.

The results of our field research indicate that 54% of all foreign R&D facilities within the Netherlands are linked to another activity of that foreign company situated in the Netherlands. In 85% of these cases it concerns a connection with manufacturing. This result gives some indication about the importance of market considerations with regard to foreign R&D investments, which was referred to in our literature review as being home-base exploiting R&D or adaptive R&D (see Section 7.3.1).

7.4 LOCATION FACTORS OF R&D: ECONOMETRIC ANALYSIS

It is unclear whether the results from the existing literature on R&D location factors can be generalised to a larger selection of countries, since most of these studies survey 300 firms at most within only a small number of countries (cf. Pearce, 1999; Hakånson and Nobel, 1993; Fors, 1998; Florida, 1997; Medcof, 1997; Patel and Vega, 1999; Kuemmerle, 1997, 1999; Kumar, 2001; Le Bas and Patel, 2007). Only a limited number of studies use aggregated country-level data on foreign R&D activities (cf. Papanastassiou, 1997a, 1997b; Jones and Teegen, 2003) and even less studies have investigated MNOs' location decisions using international macroeconomic panel data (e.g. Doh *et al.*, 2005; Cantwell and Piscitello, 2002). To circumvent the problem of representativeness that most survey studies suffer from, we have conducted an econometric analysis with international macro- and industry-level data. The aim of this analysis is to verify and complement the results that we have found in the literature and in our field study. In addition, the econometric analysis enables us to quantify the importance of the location factors of R&D.

Two models are estimated. The first model tries to explain the R&D activities of foreign affiates through factors such as the value added of foreign affiliates, R&D capital and human capital. Model 1 is a random effects model using unbalanced panel data. The second model represents an error correction model with fixed effects and attempts to explain the foreign ownership of domestic inventions over time. We will discuss the design and estimation results of both models 1 and 2 in Sections 7.4.2 and 7.4.3, respectively. In the next section, we will first consider the data and variables used in the econometric analysis.

7.4.1 Data and variables

Table 7.4 shows the variables used in our econometric analysis, as well as their data sources and some descriptive statistics. Below we provide more information on these variables.

Table 7.4 Variables, data sources and descriptive statistics

Variable	Description	Source	Mean	Median	Std. Dev.	Scale	Observations
IRD/GDP	R&D investments of foreign affiliates as a percentage of GDP (national currency)	OECD, AFA database	0.29	0.26	0.24	Max: 1.73 Min: 0.16	Model 1: 122
PATENT/LABFOR	number of foreign-owned patents (EPO) of domestic inventions in relation to the labour force (per thousand individuals)	OECD, Patent Database	2.97	1.93	3.16	Max: 17.33 Min: 0.02	Model 2: 441
$VA^{foreign}/GDP$	value added of foreign affiliates relative to GDP (national currency)	OECD, AFA database	11.24	6.83	10.31	Max: 44.6 Min: 0.30	Model 1: 83
$RDC^{private}/GDP$	private R&D capital in relation to GDP (national currency)	OECD, Main Science and Technology Indic.	5.58	5.30	3.49	Max: 15.27 Min: 0.17	Model 1: 120 Model 2: 418
RDC^{public}/GDP	public R&D capital in relation to GDP (national currency)	OECD, Main Science and Technology Indic.	3.52	3.73	1.22	Max: 5.92 Min: 0.64	Model 1: 120 Model 2: 415
EDUC	average years of education of the working-age population	Bassanini and Scarpetta (2001)	10.63	11.00	1.63	Max: 13.5 Min: 6.4	Model 2: 378
$HRST^{core}$	number of employees in science and technology (percentage of total employment)	Eurostat (labour force survey)	15.64	15.79	3.34	Max: 23.41 Min: 8.34	Model 1: 69
RDW	average labour costs of R&D personnel (in US$ (× 10,000) per fte, constant prices of 1995 and US$ PPP)	OECD, Economic Outlook nr. 74	5.94	5.83	1.18	Min: 8.90 Min: 3.72	Model 1: 87 Model 2: 335
IPR	index of a 1 to 5 scale based on five underlying factors[122]	Ginarte and Park (1997) and Park and Wagh (2002)	4.02	4.04	0.47	Max:5.00 Min: 2.76	Model 1: 99
GDP	gross domestic product (constant prices of 1995, in millions of $US PPP)	OECD, Economic Outlook, nr. 74	818.52	199.48	1521.24	Max: 9039 Min: 37.62	Model 2: 431

Commentary: the inward R&D intensity, the private and public R&D capital intensity, and value added of foreign firms (in relation to GDP) are expressed as percentages to simplify the interpretation of the descriptive statistics. In the regression analyses, however, these variables are expressed as ratios. This difference does not alter the regression results.

[122] The five indicators are 1) coverage (the subject matter that can be patented); 2) duration of protection (length of protection); 3) enforcement (the mechanisms for enforcing patent rights); 4) membership of international patent treaties (including the Paris Convention and Revisions, the Patent Cooperation Treaty and the Protection of New Varieties); 5) restrictions on patent rights (for example compulsory licensing).

Dependent variables: foreign R&D investments and foreign ownership of domestic inventions
Two dependent variables are used to explain the technological activities of foreign MNOs in a country. In model 1, the dependent variable encompasses total R&D activities of foreign affiliates (*IRD*) in a country. The data originate from the OECD Activities of Foreign Affiliates (AFA) database.[123] In our analysis we consider 13 countries over the period 1990-2002 (for additional information, see OECD, 2004a). The data are standardised by dividing foreign R&D investments by gross domestic product (*GDP*).

In model 2, the dependent variable that we use is foreign ownership of domestic inventions ($PATENT^{foreign}$), which are registered at the European Patent Office (EPO).[124] Although patents are no ideal indicator for innovation (cf. Pavitt, 1988; Acs and Audretsch, 2005), they measure both technological and economic significance (Furman *et al*., 2002; Griliches, 1990). Hence, we can reasonably assume that foreign-owned patents of domestic inventions are a useful indicator of the technological activity of foreign firms in a certain country. An important difference with inward R&D investments as an indicator is that patents are a 'throughput' indictor in the innovation process rather than an input indicator, such as R&D. In our estimations, we have to account for the fact that patents are a 'throughput' indicator by using lags of the explanatory variables (see also Section 7.4.3). Data on foreign ownership of domestic patents registrations (EPO) are available in the OECD Patent Database. In our econometric analysis we use data for 25 countries over the period 1981-2001. The data on foreign ownership of domestic inventions are expressed in relation to the labour force (*LABFOR*) to adjust for the size of countries.

Next, the aim is to define a set of explanatory variables that is expected to influence a country's relative attractiveness for foreign technological activities. Based on the literature – discussed in Section 7.3.1 – we identified two main motives for conducting R&D activities abroad. First of all, many R&D location decisions are based on market considerations. This implies that firms establish R&D abroad to adapt centrally created products and technologies to local market conditions and to support their foreign production facilities in order to achieve this (corresponding with the *HBE strategy* or *adaptive R&D strategy*). Secondly, an important motive to set up foreign R&D is to gain access to state-of-the-art knowledge and skills and to absorb spillovers that sprout from foreign technological activities (corresponding with *HBA strategy* or *access to science strategy*). In the remainder of the current section (i.e. Section 7.4.1) we will describe the variables in which these two main motives are incorporated.

[123] Formally, a distinction should be made between R&D investments conducted from a research function perspective and from a development function perspective, because the location determinants of both types of investment flows differ to a large extent (see Von Zedtwitz and Gassmann, 2002; Chapter 4 of this thesis). The problem is that there are no data available to make a distinction between different types of R&D investments. Consequently, we consider R&D investments as a whole in our macro analysis.

[124] Foreign ownership of domestic inventions is one of the measures of globalisation of technological activities. It refers to the number of patents invented domestically and owned by non-residents. It expresses the extent to which foreign firms control domestic inventions. Foreign ownership includes inventions in which the inventor country shares ownership (co-owned inventions), but this share is frequently a small part of the total of cross-border inventions (OECD, 2007, p. 162).

Independent variable: value added of foreign businesses in a country

A variable that is supposed to cover the HBE strategy of MNOs is the value added of foreign establishments in a country ($VA^{foreign}$) as a ratio of gross domestic product (*GDP*). This variable may explain the part of foreign R&D that is conducted to support production and to adapt products and technologies. Cornet and Rensman (2001) argue that a firm is more likely to select a country for setting up new R&D activities in which it is already established with a production facility, distribution subsidiary or research and development laboratory. The value added of foreign affiliates is a variable that is available in the OECD AFA database. In our second model, in which we try to explain the foreign ownership of domestic inventions, GDP is included as an independent variable related to the HBE strategy. The underlying reason is that the economic size of a country could influence its attractiveness for foreign R&D, because of the large market it offers (see, for example, Fors, 1998; Doh *et al.*, 2005).

Independent variable: R&D capital stock

Two variables that relate to the HBA strategy of MNOs are the stock of private R&D capital ($RDC^{private}$) and public R&D capital (RDC^{public}) in a country. Both variables are expressed as a ratio of GDP (*GDP*), and hence are expressed as R&D capital *intensities*. The stock of R&D capital, private and public, is a proxy for a country's innovative capacity. The decision to locate in countries where R&D capital is abundant, and thus innovative capacity is strong, may be a key strategic decision, because it offers a high potential of knowledge spillovers. These spillovers generate competitive advantages by enhancing access to new knowledge, thereby lowering R&D costs, and boosting innovative output (see Feldman, 2000). Including R&D capital as an independent variable is also in accordance with research by Mota and Brandão (2005). For R&D-oriented manufacturing firms, the more traditional location factors, e.g. land and labour costs, lose importance, whilst R&D expenditure becomes more relevant. The stock of R&D capital is calculated by the accumulation of R&D expenditure from the past, while taking depreciation of the existing stock of R&D capital into account due to the obsolescence of knowledge (see Annex 2 for an explanation how to calculate the R&D capital stock).[125] Data on R&D expenditure are taken from the OECD Main Science and Technology Indicators.

Independent variable: human capital

Another variable that relates to the *home-base augmenting strategy* or *access to science strategy* is the supply of highly skilled personnel. One of the important reasons why firms invest in a certain location is to gain access to the pool of (cheap) high-quality human capital, especially if this pool is small in the home country. Several human capital indicators are available. First of all, the 'core' of human resources in science and technology as a ratio of total employment is included as a variable ($HRST^{core}$) in model 1.[126] The HRST variable is the most relevant human

[125] At first sight, a causality problem might arise in model 1, because foreign R&D investments are part of the calculated private R&D capital stock. This causality risk, however, is obviated, because the calculation of the private R&D capital stock implies working with lags.

[126] The 'core' of human resources in science and technology (HRST) from the Eurostat labour force survey follows a more narrow definition of human capital than total HRST and is better linked to the definition of R&D. Core

capital variable, because it is closely related to the definition of R&D. Unfortunately, this variable is unsuitable for model 2, because the data are only available for a short period of time. For model 2, alternatively, a more broadly defined human capital variable is used from Bassanini and Scarpetta (2002; 2001, p. 28), being the average number of years of education of the working-age population (*EDUC*).

Independent variables: labour costs of R&D personnel and IPR
Two remaining variables are the average labour costs of R&D personnel (*RDwages*) and intellectual property rights (*IPR*). Within our labour cost variable, we discriminate between the costs of R&D researchers and R&D supporting personnel (see Erken *et al*., 2004, Annex 4, pp. 136-138). Data on labour costs are taken from the OECD Main Science and Technology Indicators. As stated earlier in this article, it is unsure whether the labour costs of R&D personnel is an important location determinant of R&D investments.[127] By including a wage cost indicator in our econometric analysis, we try to shed more light on the importance of this variable for foreign technological activities. Thursby and Thursby (2006) find strong evidence that well-developed intellectual property rights matter for international R&D activities. We include an IPR variable (*IPR*) developed by Ginarte and Park (1997) in model 1 and use the data from Park and Wagh (2002).

7.4.2 Model 1: share of inward R&D

In model 1 we use a *random effects model* to estimate the determinants of R&D activities conducted by foreign affiliates. The benefit of the random effects model is that information from the *between* (i.e. variation between countries) and *within* dimensions (variation over time) are combined in an efficient way (Verbeek, 2004, p. 347 ff). The random effects model is especially suitable when few observations are available and efficient use of the data is required. A central assumption of random effects models is that the random effects are uncorrelated with the explanatory variables. In order to assess whether our model meets this assumption, we performed a Hausman (1978) test along with each estimation to compare the fixed and random effects estimates of coefficients (for further reading see Verbeek, 2004, p. 251 and Baltagi, 2001, p. 65). The test results provide little evidence against the null hypothesis that there is no misspecification, thus the random effects model seems an appropriate estimator. Our random effects model for country *i* and year *t* is specified as follows:

HRST covers the following ISCO classifications (ISCO = International Standard Classification of Occupations): professionals (ISCO-2) and technicians & associate professionals (ISCO-3).

127 On the one hand Cornet and Rensman (2001), Edler *et al.*, (2001) and Jones and Teegen (2004) find no major influence of the magnitude of labour costs on R&D location decisions by MNOs, while on the other hand, Kumar (2001), The Economist (2004) and our own field study (see also Buck Consultants International, 2004) do perceive a significant effect of wage costs.

$$\log(Y_{i,t}) = \beta_0 + \beta_1 \log X^1_{i,t} + \beta_2 \log X^2_{i,t} + \beta_3 \log X^3_{i,t} + \varepsilon_{i,t} \tag{7.1}$$

where

$Y_{i,t}$ = $IRD_{i,t}/GDP_{i,t}$
$X_{i,t}^{1}$ = $VA_{i,t}^{foreign}/ GDP_{i,t}$
$X_{i,t}^{2}$ = $RDC_{i,t}^{private}/ GDP_{i,t}$
$X_{i,t}^{3}$ = $HRST_{i,t}^{core}$
$\varepsilon_{i,t}$ = $\zeta + \lambda + \eta$ (error term)

$$\log(Y_{i,t}) = \beta_0 + \beta_1 \log X^1_{i,t} + \beta_2 \log X^2_{i,t} + \beta_3 \log X^3_{i,t} + \beta_4 \log X^{\phi}_{i,t} + \gamma(\tau) + \varepsilon_{i,t} \tag{7.2}$$

where

$X_{i,t}^{\phi}$ = $RDC_{i,t}^{public}/ GDP_{i,t}$
= $RDW_{i,t}$
= $IPR_{i,}$
τ = trend variable
$\varepsilon_{i,t}$ = $\zeta + \lambda + \eta$ (error term)

for
(i,t) ∈ (Canada, 1990-2002), (the Czech Republic, 1997-2002), (Finland, 1997-2001), (France, 1994-2002), (Germany, 1993-2001), (Hungary, 1992-1998), (Ireland, 1991-2001), (Japan, 1991-2001), (the Netherlands, 1995-2001), (Spain, 1991-2001), (Sweden, 1991-2001), (the United Kingdom, 1994-2001), (the United States, 1990-2002)

Equation (7.1) is the baseline equation of model 1, where *Y* represents inward R&D investments (*IRD*) in relation to gross domestic product (*GDP*), β_0 is a constant term and 'log' denotes a natural logarithm. X^1 indicates value added of foreign affiliates ($VA^{foreign}$) in relation to GDP, which covers the home-base exploiting strategy of MNOs to invest in R&D. X^2 represents the private R&D capital intensity ($RDC^{private}/GDP$), i.e. the amount of R&D capital in relation to GDP. X^3 is a human capital variable measuring the amount of 'core' *human resources in science and technology* ($HRST^{core}$) as a percentage of total employment. Both X^2 and X^3 relate to the home-base augmenting strategy of MNOs. Within a random effects model, the error term $\varepsilon_{i,t}$ consists of three components (Pindyk and Rubinfeld, 1998, p. 254 ff): a cross-section error component (ζ), a time-series error component (λ) and a combined error component (η).

Besides the estimation of our baseline equation (7.1), we want to examine a possible role of other determinants of FDI in R&D that emerge from the literature. In equation (7.2), we additively introduce the public R&D capital intensity (RDC^{public}/GDP), the wage costs of R&D personnel (*RDW*) and a variable measuring the quality of intellectual property rights (*IPR*) in our baseline equation, denoted by X^{ϕ}. We also experiment with a trend variable τ to take into account possible spurious regression results due to trended data series (Wooldridge, 2003, p. 347).

Estimation results
We use an unbalanced set of panel data for 13 countries over the period 1990-2002 to estimate our random effects model. The amount of observations for each country and variable varies over time (see design of model 1 and last column of Table 7.4), which causes a shift in the estimated time sequence and, as a result, the number of observations used in each separate model estimation.

Column (1) of Table 7.5 presents the results of our baseline estimation, including the variables X^1 to X^3. The results show that X^1 (value added of foreign affiliates) and X^2 (private R&D capital intensity) have a significant positive effect on the inward R&D intensity. The human capital variable (X^3) has an insignificant effect. Column (2) shows the baseline estimation extended with public R&D capital intensity (X^4). The effect of public R&D capital is insignificant and weak. The estimated coefficients of the other variables remain stable when compared to the estimated baseline equation in column (1). The effect of X^3 (human capital) shows a minor rise in significance.[128] In column (3) and column (4) the costs of R&D personnel (X^5) and the IPR variable (X^6) are introduced sequentially. Although both variables have a significant effect on our dependent variable, the coefficients show a counterintuitive sign. In addition, the R&D wage costs variable (X^5) interferes with our human capital variable (X^3). In column (6) we experiment with a trend variable in the baseline equation, but this variable is insignificant and does not alter the results reported in column (1). In each additional regression, the estimated parameters of X^1 (value added of foreign affiliates), X^2 (private R&D capital) and X^3 (human resources in science and technology) remain fairly stable compared to the initially-estimated coefficients in column (1). The low Durbin-Watson statistic is due to the omission of country dummies, as a result of which unexplained differences in levels between countries are expressed in serially-correlated residuals.[129]

Because our macro model 1 is based on a relatively limited number of observations, in Annex 3 we perform a robustness analysis where we re-estimate the baseline equation of model 1 using industry-level data. The results of an industry-specific fixed effects model are reported in Table A.2 and confirm the results of our macro model (Table 7.5). We also conducted separate regression analysis for individual industries (see Table A.3 in the annex).

[128] Applying a confidence level of 90% or using a one-sided t-test, the effect of human capital (X^3) can be considered significant. The critical value of a one-sided t-test (with a 95% confidence interval and 47 observations) lies at 1.68.

[129] If two or more consecutive error terms are correlated, the error term is subject to autocorrelation or serial correlation (for instance Verbeek, 2004, p. 97). In order to obviate the problem of biased t-values as a result of autocorrelation and heteroskedasticity, model 1 was estimated using White cross-section standard errors & covariance.

Table 7.5 Estimation results of model 1

Coefficients and independent variables		Y = inward R&D in relation to GDP				
		(1)	**(2)**	**(3)**	**(4)**	**(5)**
β_0	Constant	-4.01 (-4.00)	-4.06 (-3.70)	-4.27 (-3.86)	-3.16 (3.01)	-3.91 (-3.14)
β_1	Value added of foreign affiliates in relation to GDP: X^1	0.61 (8.81)	0.61 (7.30)	0.75 (8.56)	0.68 (7.76)	0.61 (5.04)
β_2	Private R&D capital in relation to GDP: X^2	0.56 (4.07)	0.50 (3.50)	0.42 (2.62)	0.47 (2.75)	0.57 (2.39)
β_3	Human resources in science and technology (core): X^3	*0.47* *(1.58)*	*0.51* *(1.89)*	*0.19* *(0.45)*	0.59 (2.20)	*0.45* *(0.11)*
β_4	Public R&D capital in relation to GDP: X^4	-	*0.07* *(0.31)*	-	-	-
β_5	Wages of R&D personnel: X^5	-	-	0.59 (4.61)	-	-
β_6	Intellectual property rights regime: X^6	-	-	-	-0.89 (3.32)	
γ	Trend	-	-	-	-	*0.001* *(0.10)*
Number of observations		48	48	37	42	48
R^2		0.49	0.53	0.57	0.52	0.48
Adjusted R^2		0.45	0.49	0.51	0.47	0.43
Durbin-Watson (D.W.)		0.85	0.80	1.36	0.82	0.86

Remarks: variables that have an insignificant effect on the dependent variable are printed in *italics* (based on a 95% confidence interval) and t-values are shown in brackets. All estimations were conducted using White cross-section standard errors & covariance (d.f. corrected).

The estimation results show that in almost each individual-specific estimation the value added of foreign affiliates (X^1) and private R&D capital (X^2) have a significant effect on R&D investments of foreign affiliates. Moreover, in many industry-specific estimations the coefficients are higher than in our macro analysis. In addition, human capital (X^3) – measured by the share of high-skilled labour – has a significant impact on R&D investments of foreign affiliates in industries that are characterised by a high inward R&D intensity (i.e. R&D investments by foreign affiliates as a percentage of value added). This is for example the case for the industries *chemicals and chemical products*; *office, accounting and computing machinery* and *electrical machinery and apparatus n.e.c.*

Interpretation

The next question is how we can interpret and translate the estimation results of model 1. The significant effect of value added of foreign firms (X^1) corresponds with the existing insights from previous empirical studies and the field study carried out by Buck Consultant International (2004). In accordance with the observations by Kuemmerle (1999), home-base exploiting R&D/adaptive R&D activities are still (substantially) intertwined with other business activities, such as production, distribution and marketing. In other words, foreign firms are more likely to locate their R&D units in a country where they are already active with a production, distribution or research facility. Because we use a logarithmic functional form, the estimated parameters can be read as long-run elasticities: if the *value added of foreign firms* in a country rises by 1% (352 million US$ on average)[130], the share of foreign R&D investments increases by 0.61% (which is approximately 15.7 million US$ on average).[131] It is fairly straightforward to interpret this outcome: if a foreign firm decides to locate a new production facility in a country which will generate 352 million US$ of value added on an annual basis, it is most likely that it will be accompanied by a HBE/adaptive R&D unit which invests 15.7 million US$ into research to support the production plant (and adapt processes and products to local market conditions).

The significant effect of the R&D capital intensity (X^2) can be interpreted in two ways. First, as the R&D capital stock embodies the stock of private knowledge in a country, the estimated positive effect is a clear indication that firms locate their R&D somewhere to capture potential knowledge spillovers (e.g. Feldman, 2000). Second, the volume of R&D capital has a 'place-to-be-effect' on potential foreign investors. Obviously, in a country where R&D activity is high, framework conditions for research are in place and the innovative climate is likely to be excellent. Both effects (i.e. the exploitation of knowledge spillovers and the 'place-to-be-effect') correspond with the results from a study by Cantwell and Piscitello (2002), which provides evidence that the agglomeration of R&D activities has a significant impact on the attractiveness

[130] Weighted average (constant prices in 1995, $PPP; period 1995-2000) for the Czech Republic, Finland, France, Hungary, Ireland, Japan, the Netherlands, Portugal, Spain, Sweden, Turkey, the UK and the US. Calculations are based on data from the OECD AFA database and OECD Economic Outlook, no. 74.

[131] Weighted average (constant prices in 1995, $PPP, period 1995-2001) for Canada, the Czech Republic, Finland, France, Germany, Hungary, Ireland, Japan, the Netherlands, Poland, Spain, Sweden, Turkey, the UK and the US. Calculation are based on data from the OECD AFA database and OECD Economic Outlook, no. 74.

of a location for foreign R&D companies. Before quantifying the estimated effect, we have to take into consideration that 1% additional private *R&D capital* as a percentage of GDP is realised in the long run by 1% additional *R&D investments* as a percentage of GDP on a structural basis (see, for instance, Guellec and Van Pottelsberghe de la Potterie, 2004, Annex A). Hence, the estimated effect implies that 1% additional *private R&D expenditure* as a percentage of GDP (which is on average 132 million US$)[132] increases R&D investments by foreign affiliates as a ratio of GDP in the long run by 0.56% (which is 14.5 million US$ on average, see note 131).

The estimated effect of human capital on R&D investments of foreign affiliates is less unequivocal. Although the preferred estimations of our macro model 1 (Table 7.5, column (1)) and sectoral robustness analysis (Table A.2, column (3)) do not reveal a significant impact of human capital on inward R&D investments, on a lower level of aggregation a different pattern emerges. Some industries that are characterised by a high inward R&D intensity and a high rate of technological activity in general, also show a significant impact of human capital. For example, in the chemical industry a 1% point higher share of high-skilled labour (the average share in the chemical industry is 30.2%)[133] would increase inward R&D expenditure by an additional 3.3 million US$ on average.[134] We can conclude that at least in high-technology industries human capital seems to be an important location factor for foreign R&D investments. In the time series model 2 we will further analyse the effect of human capital econometrically.

7.4.3 Model 2: foreign-owned patents

Developments over time yield important information, but the available data series on foreign R&D investments are not long enough to conduct time series analysis. The OECD Patent Database, however, provides possibilities to construct long time series with respect to foreign ownership of domestic inventions. In our second model, we attempt to explain the development of *foreign ownership of domestic inventions* over time.

Finding ‘spurious’ or nonsense regressions is a serious risk when using panel data analysis, because the dependent and independent variables are often trended over time (Granger and Newbold, 1974). This risk is more prominent when using variables that are non-stationary. We checked if our variables are stationary by using augmented Dickey-Fuller (ADF) tests (Dickey and Fuller, 1979, 1981; Verbeek, 2004, p. 268 ff). Various ADF tests for the dependent and independent variables learn that most variables are non-stationary series. An appropriate way to manipulate non-stationary series is by first differencing. However, differencing the data is

[132] OECD average (constant prices in 1995, $PPP) for 1995-2002.

[133] Weighted average (constant prices in 1995, $PPP; period 1995-2005) for the Czech Republic, Finland, France, Ireland, Japan, the Netherlands, Portugal, Sweden, the UK and the US. Weights were applied based on GDP shares of countries.

[134] Weighted average (constant prices in 1995, $PPP; period 1995-2005) for the Czech Republic, Finland, France, Ireland, Japan, the Netherlands, Portugal, Sweden, the UK and the US. Calculations are based on data from the OECD AFA database and EU KLEMS. Absolute values were converted using industry-specific purchasing parities (see Van Ark *et al.*, 2003).

counterproductive, since it obscures the long-run relationship between our dependent and independent variables (see Greene, 2000, p. 790). A more interesting alternative to analyse trended variables is by using an *error correction model (ECM)* on cointegrated time series (see Greene, p. 789 ff; Verbeek, 2004, p. 314 ff). An error correction model is a dynamic model that allows for simultaneous estimations of both long-run equilibrium values and short-term dynamics (see, for instance Wooldridge, 2004, p. 620 ff). Abstracting from lags of the independent variables, we can define the following general ECM for country *i* and year *t*:

$$\Delta \log(Y_{i,t}) = \beta_1 \Delta \log X^1_{i,t} + \beta_2 \Delta \log X^2_{i,t} + \beta_3 \Delta \log X^3_{i,t} + \beta_4 \Delta \log X^4_{i,t} + \beta_5 \Delta \log X^5_{i,t} +$$
$$\lambda \left[\log(Y_{i,t-1}) - \begin{pmatrix} \beta_0 + \beta_6 \log X^1_{i,t-1} + \beta_7 \log X^2_{i,t-1} + \beta_8 \log X^3_{i,t-1} \\ + \beta_9 \log X^4_{i,t-1} + \beta_{10} \log X^5_{i,t-1} \end{pmatrix} + \sum_i f_i DUM_i \right] + \varepsilon_{i,t} \tag{7.3}$$

where

$Y_{i,t}$ = $PATENT_{i,t}^{foreign}/LABFOR_{i,t}$
$X_{i,t}^{1}$ = $RDC_{i,t}^{private}/GDP_{i,t}$
$X_{i,t}^{2}$ = $RDC_{i,t}^{public}/GDP_{i,t}$
$X_{i,t}^{3}$ = $EDUC_{i,t}$
$X_{i,t}^{4}$ = $RDW_{i,t}$
$X_{i,t}^{5}$ = $GDP_{i,t}$
λ = error correction term
DUM = country dummy
ε = idiosyncratic error term

for

i $\in$ (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States)
t $\in$ (1981,…, 2001)

In equation (7.3), Y represents the number of domestic inventions owned by non-residents (*PATENT*) per thousands of the labour force (*LABFOR*). β_0 is a constant term, 'log' denotes a natural log, X^1 and X^2 symbolise private and public R&D capital intensity ($RDC^{private}/GDP$ and RDC^{public}/GDP). X^3 is a human capital variable expressed as the average years of education of the working-age population (*EDUC*). X^4 is an indicator for the R&D labour costs (*RDW*), X^5 represents the volume of gross domestic product (*GDP*), *DUM* is a dummy for country *i* and ε refers to an idiosyncratic error term.[135] The error correction term λ should be significant and negative for the model to have a cointegration vector. If Y and the vector of independent variables X are integrated of order one $I(1)$ and have a long-run relationship, there must be a

[135] Country dummies are included to take account of unobserved heterogeneity.

force which pulls the equilibrium error back towards zero (Verbeek, 2004, p. 318). A significant negative coefficient for λ does exactly this: if, for instance, $Y_{t-1} > X_{t-1}$, then Y in the previous period has overshot the equilibrium; because $\lambda < 0$, the error term pushes Y back towards the equilibrium (see Wooldridge, 2004, p. 621). In general, if a dependent variable Y and a vector of independent variables X have an error correction specification, then conversely the Granger representation theorem (Granger, 1983; Engle and Granger, 1987) on cointegration holds, which means that series are necessarily cointegrated (Verbeek, 2004, p. 319; Greene, 2000, p. 793).

Because patents are the results of R&D efforts in the past, we also need to determine how many years each independent variable has to be lagged. This allows us to determine causality of the independent variables on the dependent variable as well. To determine the amount of lags of each independent variable, the following econometric estimation technique is used for country i and year t:

$$\begin{aligned}\log Y_{i,t} &= \alpha_0 + \phi(\beta_0 \log X_{i,t} + \beta_1 \log X_{i,t-1} + \beta_2 \log X_{i,t-2} + \beta_3 \log X_{i,t-3} \\ &+ \beta_4 \log X_{i,t-4} + (1-\beta_0-\beta_1-\beta_2-\beta_3-\beta_4) X_{i,t-5}) + \sum_i f_i DUMMY_i\end{aligned} \tag{7.4}$$

Applying this equation on each of our independent variables leads to the following optimal lag structure: the R&D capital variables X^1 and X^2 are both lagged three years, whereas the remaining variables X^3, X^4 and X^5 are lagged two years. Adopting this optimal lag structure, model 2 ultimately becomes:

$$\begin{aligned}\Delta\log(Y_{i,t}) &= \beta_1\Delta\log X^1_{i,t-3} + \beta_2\Delta\log X^2_{i,t-3} + \beta_3\Delta\log X^3_{i,t-2} + \beta_4\Delta\log X^4_{i,t-2} + \beta_5\Delta\log X^5_{i,t-2} \\ &+ \lambda\left[\log(Y_{i,t-1}) - \begin{pmatrix}\beta_0 + \beta_6\log X^1_{i,t-4} + \beta_7\log X^2_{i,t-4} + \beta_8\log X^3_{i,t-3} \\ +\beta_9\log X^4_{i,t-3} + \beta_{10}\log X^5_{i,t-3}\end{pmatrix} + \sum_i f_i DUM_i\right] + \varepsilon_{i,t}\end{aligned} \tag{7.5}$$

Estimation results

Table 7.6 shows the regression results of model 2, using data for 21 OECD countries over 21 years (1981-2001). Column (1) shows the initial estimation results with all independent variables included. In the short run, only GDP (X^5) has a significant (positive) effect on the amount of foreign-owned patents of domestic inventions. This means that in *the short run* knowledge investments are largely market-driven: the larger the host market of a country, the greater the need for local adaptation of goods and services. As a consequence, HBE/adaptive foreign direct investments in R&D are required to facilitate such adjustments. The importance of GDP as a location factor for technological activities of MNOs is in accordance with Doh *et al.* (2005) – although they do not distinguish between short- and long-run effects.

Table 7.6 Estimation results model 2

Coefficients and independent variables		*Y* = foreign ownership of domestic inventions in relation to labour force		
		(1)*	**(2)**	**(3)****
β_0	Constant	-7.82 (-3.72)	-10.47 (-6.09)	-8.14 (-8.21)
β_1	Private R&D capital in relation to GDP (ΔX^1)	*0.78* *(1.17)*	*0.55* *(0.97)*	*-0.38* *(-0.54)*
β_2	Public R&D capital in relation to GDP (ΔX^2)	*0.52* *(0.61)*	-	-
β_3	Average years of education (ΔX^3)	*1.52* *(1.41)*	1.95 (2.06)	3.00 (3.15)
β_4	Wages of R&D personnel (ΔX^4)	*0.10* *(0.23)*	-	-
β_5	GDP (ΔX^5)	2.35 (2.87)	1.52 (2.15)	*1.03* *(1.29)*
β_6	Private R&D capital in relation to GDP (X^1)	0.48 (2.39)	0.46 (2.88)	0.55 (3.22)
β_7	Public R&D capital in relation to GDP (X^2)	*0.59* *(1.82)*	-	-
β_8	Average years of education (X^3)	4.17 (4.51)	4.68 (6.33)	6.00 (9.71)
β_9	Wages of R&D personnel (X^4)	*0.18* *(0.29)*	-	-
β_{10}	GDP (X^5)	*-2.20* *(-1.70)*	*-0.96* *(-0.87)*	0.96 (5.40)
λ	Error correction term	-0.65 (-5.60)	-0.59 (-6.04)	-0.56 (-6.95)
Country dummies?		Yes	Yes	Yes
Observations (N)		248	317	338
R^2		0.37	0.31	0.31
Adjusted R^2		0.29	0.25	0.26
Durbin-Watson (D.W.)		2.16	2.23	2.28

Remarks: variables that have an insignificant effect on the dependent variable are printed in *italics* (based on a 95% confidence interval) and t-values are shown in brackets. Standard errors have been adjusted for heteroskedasticity and autocorrelation in the residuals (Newey-West HAC Standard Errors & Covariance).

* Estimation for a restricted sample without the countries Belgium, New Zealand, Norway and Switzerland.

** The equation adopts the lag structure presented in equation (7.3): in the dynamic part of the equation no lags were used, whereas in the part concerning long-run relationships the independent variables were all lagged one year.

The significant impact of the GDP variable could also mean that foreign knowledge investments are cyclically sensitive in the short run: countries experiencing an economic boom will attract more foreign knowledge investments compared to countries that have a weak position within the business cycle. In the long run, however, GDP has no significant impact on foreign ownership of domestic inventions. Two variables reveal a significant positive impact on the dependent patent variable in the long: the private R&D capital intensity (X^1) and human capital (X^3). The wage costs variable and public R&D capital intensity do not have a significant impact on foreign-owned patents in either the short or long run and will be dropped from the model. Finally, our error correction term (λ) shows a significant negative effect, which means that our model has a cointegration vector.

In column (2) we re-estimate our error correction model with exclusively the variables that have a significant effect in the initial estimation (column (1)). In column (2) the average duration of education has a significant positive effect on the amount of foreign-owned patents in the short run. Besides this difference, the regression outcome is fairly similar to full model inference (column 1): GDP only has a significant positive impact in the short run, and the human capital variable and private R&D capital both have a significant positive effect in the long run (the magnitude of the coefficients in both estimations are approximately equal). Again, the model passes the cointegration test.

As a robustness check, we also experimented with different lags of each independent variable. It turns out that the most important results are not sensitive to differences in the lag structure of any chosen specification. To illustrate this: column (3) shows a re-estimation of the regression reported in column (2), but adopts the lag structure of equation (7.3). The results approximate the ones reported in column (2), with the exception that GDP shows a significant positive effect in the long instead of the short run.

Interpretation
The estimation results from our preferred estimation in column (2) are in accordance with the results from model 1 and the field research. The *stock of private R&D capital* is an important factor for technological activity, as firms can exploit knowledge spillover effects at locations where R&D activity is high. In addition, R&D capital has as an important signalling effect to MNOs (the ‘place-to-be-effect’). The estimated coefficients can be interpreted as long-run elasticities, which means that a 1% increase of R&D expenditure as a percentage of GDP (which amounts to 132 million US$ on average) will cause a rise in the number of foreign-owned patents (as a ratio of the total labour force) by 0.46% (which is on average 2.4 foreign-owned patents of domestic inventions).[136]

[136] This figure is an unweighted average over the period 1990-2001 for Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US.

The significant influence of the *average duration of education* corresponds with the results from the field research and the industry-specific estimations of model 1 (Table A.3). The impact of our human capital variable can be interpreted in a similar way as the effect of private R&D capital: if the average number of years of education increases by 1%, the number of foreign inventions (as a ratio of the total labour force) will rise by 4.68%. In absolute terms, this means that an increase in the *average duration of education* of the working-age population by one month would lead to an increase of foreign-owned patents by 3.67%, which approximates 18.9 patents on average (see footnote 136). Although the effect of the human capital variable is much higher, one must bear in mind that one month extension of the duration of education of the working-age population is more difficult to achieve than a 1% increase in private R&D intensity.

7.5 CLOSING COMMENTS

In this chapter we empirically analyse the importance of the location factors of R&D. We adopt a multi-level perspective covering empirical results from (1) the literature, (2) a field study and (3) an econometric analysis based on macro- and industry-level panel data. The three perspectives point out that (1) *the availability of highly skilled personnel*, (2) *the value added of foreign firms* and (3) *the stock of private R&D capital* are the most important factor for attracting foreign R&D activities. The top three most important location factors for R&D is complemented by (4) *international accessibility* and (5) *the quality of knowledge institutions*.

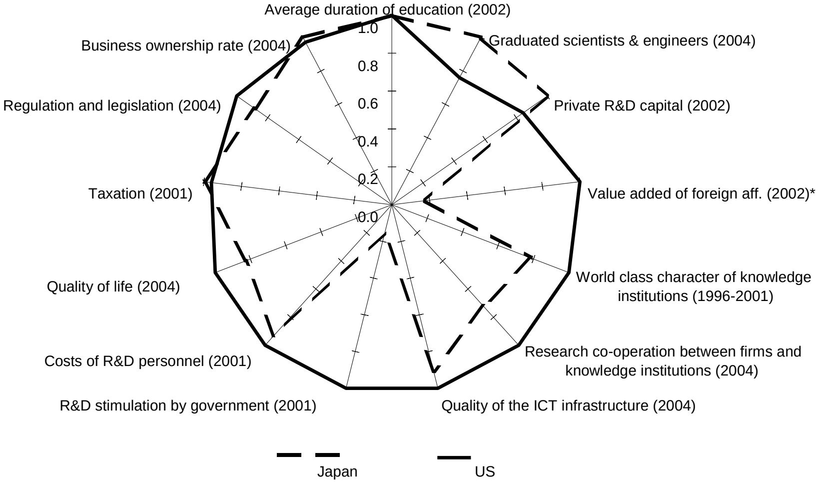
Box 7.1 The Øresund region

The Øresund region, situated on both sides of the strait (the Sound) between Denmark (Zealand, Copenhagen) and Sweden (Skåne, Malmö), is a prime example of a highly sophisticated business area. The position of this region in Europe with regard to the above-mentioned R&D location factors is excellent. It hosts some 20 universities, including the Technical University of Denmark, the University of Copenhagen, and the Swedish University of Agricultural Sciences Alnarp, in which over 120,000 students are enrolled. The Copenhagen airport guarantees the region's accessibility. Its role as a strategic hub and gateway to the Baltic is strengthened even further by the region's three large ports. There are numerous science parks and research institutions (outside the universities), and the quality of science is high. Measured in terms of scientific research publications, it ranks fifth in Europe. In the period 1998 to 2000 Øresund received a major share of direct investments in Denmark and Sweden. Multinational corporations such as Daimler/Chrysler, Unilever, Orange and Novo Nordisk, have recently established themselves in Sweden. The Øresund region houses many of these companies' (research) operations. Furthermore, some well-known companies have made acquisitions in the region: Intel has bought GIGA (an integrated circuit design firm), and Pfizer has acquired Pharmacia. Finally, over 70% of foreign-owned enterprises in Denmark are located in the Greater Copenhagen Area.

We claim that the quality of these location factors determines, to a large extent, the attractiveness of countries and regions for R&D activities from abroad. Two examples are presented in this final section to support this claim. First, in Box 7.1 a region is discussed that attracts a high level of foreign R&D activities, being the Øresund region. This region has an excellent score on the five most important location factors and, as a consequence, manages to attract a large amount of foreign investments (including R&D investments).

The second example discusses differences between the R&D investment climate of Japan and the US, two relatively closed economies. Japan attracts less foreign R&D investments compared to the US (see Table 7.1). The benchmark of the R&D investment climate between Japan and the US is presented in a so-called spider diagram (see Figure 7.1). This diagram shows on which location factors a country performs relatively better or worse than the country it is compared with. The score between two countries is normalised on a scale from 0 to 1.

Figure 7.1 Comparison of R&D investment climate between Japan and the US [137]



* Value added of foreign affiliates as a % of GDP in Japan could only be calculated for the year 2001.

The country that has the best position on a certain location factor is given a score of 1.[138] The selection of location factors for the benchmark analysis is based on Table 7.3 and the results from the econometric analysis (Section 7.4).[139]

[137] Annex 1 provides more information on the definition of the location factors and the data sources. The year of observation is shown between brackets.

Japan performs better than the US on the most important location factor: the availability of highly skilled personnel.[140] The average years of education in the US is on par with Japan, but with respect to the share of *graduates* in science and engineering (per 1,000 inhabitants aged 20-29) the performance of the US is below average.[141] The low influx of scientists and engineers could have major negative implications for the US regarding the future attractiveness for foreign R&D. Furthermore, Japan has a more favourable position on private R&D capital. How is it possible that the US attracts more R&D than Japan (Table 7.1)? This is likely due to the fact that the US outperforms Japan on all other location factors of R&D. For instance, the world-class character of US' knowledge institutions and the possibilities for co-operation within the US are attractive for foreign R&D firms. More important, however, is the weak position of Japan on the *value added of foreign firms*.[142] Clearly, overall business activity by foreign firms is very low in Japan, which – to a large extent – can be attributed to the autarkic nature of the Japanese economy (even more than the US economy, see, e.g., Figure 6.4 in Chapter 6). The relative good performance of Japan on the other important location factors indicate that if Japan manages to attract more foreign business activities in general, the inward R&D investments are likely to increase substantially.

The two examples illustrate the value of the results found in this chapter for policymakers who are concerned with foreign direct investments in R&D on the one hand and offshoring of R&D activities on the other hand. Providing policymaker with new insights into relevant R&D location factors enables them to better understand their country's performance on foreign R&D and identify opportunities to improve the R&D investment climate. In the Chapter 8 we discuss a taxonomy how to benchmark the quality of R&D investment climate. Since we use a multi-level approach (i.e. three different methods of examination) in this chapter, we feel that we have identified a robust set of R&D location factors that will be relevant for many countries.

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[138] To give an example, the share of graduated scientists & engineers in Japan in 2004 is 13.4% (per 1,000 inhabitants aged 20-29 years). In the US, this figure is 10.2% in that year. These scores imply that in the spider diagram Japan receives a score of 1 on this location factor (best performing country) and the US receives a score of 0.76 (= 10.2/13.4).

[139] Some location factors have been left out of the selection because of data problems which makes quantification difficult (for instance, the international accessibility or the proximity of lead users/strategic partners). Furthermore, unimportant location factors are not included in the benchmark analysis. To quantify the relative position of Japan and the US, we have used 'hard' data from the OECD (OLIS) and Eurostat whenever possible. On some location factors, however, hard data is unavailable. In this case, we have complemented our analysis with 'softer' data from alternative sources, such as the World Competitiveness Yearbook by IMD. Annex 1 provides more information on the data sources used in the benchmark analysis.

[140] Although the location factor 'international accessibility' has not been included in this analyses because of lack of data, we assume that the US has a better score on this factor than Japan, given the more central geographical location of the US.

[141] Figures are from Eurostat, Structural Indicators. Other figures from the OECD (2004b) indicate that the US is among the weakest performing countries with regard to the share of graduates in science and technology as a percentage of total graduates.

[142] Japan also has a very low score on R&D stimulation incentives by the government. However, this location factor is less relevant than the value added of foreign affiliates.

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ANNEX 1. Sources used in benchmark of the R&D investment climate (Section 7.5)

Location factors	Sources
1) Availability of highly qualified personnel: Average years of education of the working-age population; Science and engineering graduates per 1000 of population aged 20-29	Bassanini & Scarpetta (2001, 2002), Eurostat Structural Indicators, Eurostat database, OECD (2004b)
2) Private R&D capital as a % of GDP	OECD Main Science & Technology Indicators
3) Value added of foreign affiliates in a country as % of GDP	OECD AFA database, OECD STAN database, OECD Structural Statistics for Industry and Services
4) International accessibility: number of km roads and railway as a % of population	IRF World Road Statistics 1997-2003, UNECE
5) World-class character knowledge institutions/universities: share of citations received from corporate research papers worldwide, relative to the share of the domestic publication output in the worldwide publication output, 1996-2001; Alternative indicator: public R&D capital	Netherlands Observatory of Science and Technology (2003), based on ISI data, OECD Main Science and Technology Indicators
6) Innovation co-operation between firms and knowledge institutions	Statistics Netherlands (2003), Eurostat database, IMD (World Competitiveness Yearbook)
7) Capacity and quality ICT/telecom infrastructure	ITU (Digital Access Index), EIU (e-readiness rankings)
8) R&D financing by government: R&D subsidies and credits, R&D tax incentives and R&D orders by the government	OECD beta index, OECD Science Technology & Industry Scoreboard, OECD Main Science & Technology Indicators
9) Costs of R&D personnel (taking into account the composition of R&D personnel)	OECD Main Science & Technology Indicators
10) Quality of life	IMD (World Competitiveness Yearbook)
11) Taxes: total tax revenues as a % of GDP	OECD Taxation Statistics
12) Regulation and legislation: labour market regulation, competition legislation, financial stability and environmental laws	IMD (World Competitiveness Yearbook)
13) Business ownership rate: business owners as a % of the working force	EIM Compendia dataset

ANNEX 2. Calculation of R&D capital stock

R&D capital stocks are calculated using the perpetual inventory method. This appendix is largely based on Guellec and Van Pottelsberghe de la Potterie (2004).

Equation (A.1) illustrates the relationship between R&D capital in year *t* and year *t*-1 (for country *i* and industry *j*) and R&D investments in year *t*:

$$RDK_{i,j,t} = RD_{i,j,t} + (1-\delta)RDK_{i,j,t-1} \tag{A.1}$$

In equation (A.1), *RD* represents R&D expenditure, *RDK* denotes the R&D capital stock and δ the annual depreciation rate of R&D capital. R&D expenditure are available for only a short period of time. Under certain assumptions it is possible, however, to calculate the initial stock of R&D capital. If RD_0 represents the first data point of a series of R&D expenditure ($t = 0$) and we assume a constant annual growth rate of the past investments (denoted by *g*), then the initial R&D capital stock can be calculated as follows:

$$RDK_0 = RD_0 + (1-\delta)\psi RD_0 + (1-\delta)^2\psi^2 RD_0 + (1-\delta)^3\psi^3 RD_0 + ... \tag{A.2}$$

where $\psi = \dfrac{1}{1+g}$ (*g* is the growth rate of R&D expenditure)

Equation (A.2) equals:

$$RDK_0 = \frac{RD_0}{1-\lambda(1-\delta)} \tag{A.3}$$

The depreciation rate of R&D capital (δ) is usually fixed at 15%. Griliches (2000, p. 54) refers to this 15% as the *'"conventional" 15 percent figure for the depreciation of R&D capital'*. The annual growth rate (*g*) of R&D expenditure can be calculated using the following formula:

$$X_n = X_0 \times (1+g)^n \tag{A.4}$$

In (A.4), X_n denotes the last data point of a series of R&D expenditure with *n* years of observation and X_0 is the first data point. Equation (A.4) can be rewritten as:

$$g = \left(\frac{X_n}{X_0}\right)^{\frac{1}{n}} - 1 \tag{A.5}$$

ANNEX 3. Sectoral robustness analysis of model 1

In this annex we perform a robustness analysis using industry-level data to test the estimation results of the baseline equation of model 1 (see Table 7.5, column (1)). We use the following fixed effects model for country *i*, industry *j*, year *t*:

$$\log(Y_{i,j,t}) = \beta_0 + \beta_1 \log X^1_{i,j,t} + \beta_2 \log X^2_{i,j,t} + \beta_3 \log X^3_{i,j,t} + \sum_j f_j DUM_j + \tau + \varepsilon_{i,j,t} \qquad \text{(A.6)}$$

where

$Y_{i,j,t}$ = $IRD_{i,j,t}/GDP_{i,j,t}$
$X_{i,j,t}{}^1$ = $VA_{i,j,t}{}^{foreign}/ GDP_{i,j,t}$
$X_{i,j,t}{}^2$ = $RDC_{i,j,t}{}^{private}/ GDP_{i,j,t}$
$X_{i,j,t}{}^3$ = $HS_{i,j,t}$
DUM = dummy variable
τ = trend variable
$\varepsilon_{i,t}$ = idiosyncratic error term

for
$(i,t) \in$ (the Czech Republic, 1997-2005), (Finland, 1995-2005), (France, 1994-2005), (Ireland, 1993-2005), (Italy, 2001-2004), (Japan, 1991-2004), (the Netherlands, 1997-2004), (Portugal, 1999-2005), (Sweden, 1990-2005), (the United Kingdom, 1994-2005), (the United States, 1987-2005)

In equation (A.6), *Y* represents inward R&D investments (*IRD*) in relation to gross domestic product (*GDP*), β_0 is a constant term, 'log' denotes a natural logarithm, X^1 denotes value added of foreign affiliates ($VA^{foreign}$) in relation to GDP. X^2 represents the private R&D capital intensity ($RDC^{private}/GDP$), i.e. the amount of R&D capital in relation to GDP. X^3 is a human capital variable measuring the share of high-skilled labour (*HS*). *DUM* represents a dummy for sector *j* to pick up unobserved heterogeneity due to, for instance, exogenous technological or institutional change. Finally, we examine the necessity of a trend variable in the specification.

Data is collected for 22 industries and 11 countries. The industry classification used is visible in Table A.3.[143] The data availability across time varies with each country. Table A.1 provides additional information on each variable, such as the data source, number of observations and some descriptive statistics.

[143] The industries electricity, gas and water supply (40-41) and construction (45) were aggregated using GDP shares. The same was done to aggregate the industries wholesale and retail trade (50-52) and hotels and restaurants (55).

Table A.1 Used variables, data sources and descriptive statistics

Variable	Description	Source	Mean	Median	Std. Dev.	Obser-vations
IRD/GDP	R&D investments of foreign affiliates as a percentage of GDP (national currency)	OECD, AFA database	1.35	0.25	0.03	2115
VA/GDP	value added of foreign affiliates as a percentage of GDP	OECD, AFA database	28.12	16.28	0.38	2228
$RDC^{private}/GDP$	private R&D capital as a percentage of GDP (national currency)	OECD, Main Science and Technology Indicators 2008/2	41.12	8.77	1.21	3780
HS	hours worked by high-skilled persons engaged (share in total hours)	EU KLEMS	12.22	8.28	10.05	4290

Commentary: the inward R&D intensity, the private R&D capital intensity and the value added of foreign firms in relation to GDP are all expressed as percentages in the table to simplify the interpretation of the descriptive statistics. In the regression analyses, however, these variables are expressed as ratios. This difference does not alter the regression results.

Table A.2 shows the estimation results of our robustness analysis using industry-level data. Column (1) shows a direct estimation of the baseline equation of model 1 without dummy variables. The three variables show a significant effect on the dependent variable. In column (2) we estimate our industry-specific fixed effects model (A.6) by including industry dummies. Despite the fact that the number of observations rises dramatically in our industry-specific model when compared to the baseline estimation of model 1 in Table 7.5 (48 observations versus 1598 observations), the estimation results are remarkably similar. The effect of human capital is insignificant in both estimations and the magnitude of the coefficients of X^1 (value added of foreign affiliates: 0.88 in Table A.2 versus 0.61 in Table 7.5) and X^2 (private R&D capital: 0.55 in Table A.2 versus 0.56 in Table 7.5) is reasonably equivalent. In the estimations in column (1) and (2) the Durbin-Watson statistic is still fairly low as unexplained differences in levels between countries are expressed in serially correlated residuals. Including a trend variable seems to solve this problem (column (3)), as the Durbin-Watson statistic increases significantly. In column (4) we run some additional tests. First, we eliminate both cross-section dimensions (industry and country dimension) by including industry and country dummies in the specification. In addition, we include a first-order autoregressive term (AR(1)) in the specification to obviate any possible bias due to autocorrelation.[144] Column (4) shows that the

[144]. The AR(1) model for country *i*, industry *j* and year *t* is specified as (see Pindyck and Rubinfeld, 1998, p. 527 ff): $Y_{i,j,t} = \beta \cdot X_{i,j,t} + \mu_{i,j,t}$ and $\mu_{i,j,t} = \rho \cdot \mu_{i,j,t-1} + \varepsilon_{i,j,t}$, where X is a vector of explanatory variables and μ denotes the disturbance term. The parameter ρ is the first-order serial correlation coefficient. In effect, the AR(1) model incorporates the residual from the past observation into the regression model for the current observation.

estimation results of our model remain comparatively stable, despite the slightly lower magnitude of the estimated coefficients.

Table A.2 Robustness analysis with industry-level data

Coefficients and independent variables		*Y* = inward R&D in relation to GDP			
		(1)	**(2)**	**(3)**	**(4)**
β_0	Constant	-2.86 (-27.81)	-2.18 (-8.51)	-2.04 (-12.89)	-2.56 (-4.72)
β_1	Value added of foreign affiliates in relation to GDP (X^1)	0.92 (50.67)	0.88 (19.37)	0.88 (29.62)	0.60 (13.52)
β_2	Private R&D capital in relation to GDP (X^2)	0.64 (40.67)	0.55 (9.97)	0.54 (15.23)	0.32 (4.47)
β_3	Share of high-skilled labour (X^3)	0.08 (1.96)	*-0.04* *(-0.54)*	*-0.04* *(-0.85)*	*-0.02* *(-0.13)*
τ	Trend variable	-	-	*-0.01* *(-1.78)*	*0.02* *(1.26)*
ρ	First-order autoregressive term: AR(1)	-	-	-	0.66 (33.10)
Industry dummies?		No	Yes	Yes	Yes
Country dummies?		No	No	No	Yes
Observations (N)		1598	1598	1598	1326
R^2		0.77	0.80	0.80	0.91
Adjusted R^2		0.77	0.80	0.80	0.91
Durbin-Watson (D.W.)		0.47	0.54	2.30	-

Remarks: variables that have an insignificant effect on the dependent variable are printed in *italics* (based on a 95% confidence interval) and t-values are shown between brackets. Standard errors have been adjusted for heteroskedasticity and autocorrelation in the residuals (Newey-West HAC Standard Errors & Covariance).

In Table A.3 we present the results of random effects estimations for individual industries. The regression results show that in almost each industry-specific estimation the value added of foreign affiliates (X^1) and private R&D capital (X^2) show a significant effect on the R&D investments of foreign affiliates. Hence, for individual industries these variables prove to be important location factors for international R&D activities. In fact, in many sectors the effect of both variables on R&D investments of foreign affiliates is higher compared to the estimated effects in the macro analysis (Table 7.5) and sectoral robustness analysis (Table A.2). The effect of the human capital variable (X^3) is less unambiguous.

Table A.3 Industry-specific estimation results

	Industry-specific coefficients (ISIC codes between brackets)	Constant	Value added of foreign affiliates in relation to GDP (X^1)	Private R&D capital in relation to GDP (X^2)	Share of high-skilled labour (X^3)	Trend variable	Observations (N)	Adjusted R^2	Durbin-Watson (D.W.)
Y = inward R&D in relation to GDP	Mining and quarrying (10-14)	-6.00 (-3.79)	*0.35* *(1.58)*	0.36 (2.30)	1.00 (3.49)	*-0.13* *(-1.93)*	52	0.24	1.41
	Food, beverages and tobacco (15-16)	-3.29 (-7.69)	0.66 (4.17)	0.71 (4.37)	-0.50 (-2.39)	0.07 (5.82)	94	0.37	1.20
	Textiles, textile products, leather and footwear (17-19)	-3.64 (-2.73)	1.05 (7.16)	*0.25* *(0.58)*	*-0.23* *(-1.27)*	*0.02* *(1.72)*	82	0.35	0.81
	Wood and wood products, except furniture (20)	-3.05 (-2.80)	1.35 (6.34)	0.63 (6.80)	*0.45* *(0.75)*	*0.05* *(1.14)*	38	0.67	1.06
	Pulp, paper, paper products, printing and publishing (21-22)	*0.26* *(0.11)*	1.09 (4.35)	1.17 (3.77)	*-0.35* *(-0.86)*	*-0.03* *(-1.06)*	68	0.34	1.09
	Coke, refined petroleum and nuclear fuel (23)	-6.17 (-4.40)	0.63 (9.58)	0.66 (2.37)	1.21 (2.12)	*-0.03* *(-1.08)*	27	0.82	1.15
	Chemicals and chemical products (24)	-2.87 (-6.52)	1.04 (8.78)	0.88 (7.55)	0.25 (2.58)	0.02 (2.69)	102	0.75	0.42
	Rubber and plastic products (25)	-2.11 (-3.34)	0.85 (10.08)	0.89 (4.79)	*-0.15* *(-0.92)*	-0.01 (-0.54)	100	0.29	1.41
	Other non-metallic mineral products (26)	-2.25 (5.14)	0.85 (7.02)	0.68 (7.23)	-0.48 (-3.36)	0.02 (1.69)	105	0.50	0.95
	Basic metals (27)	-4.18 (-6.21)	0.47 (2.65)	0.49 (2.59)	0.03 (0.21)	-0.02 (-1.20)	81	0.64	1.44
	Fabricated metal (28)	-4.84 (-4.22)	0.84 (6.51)	*0.01* *(0.02)*	*0.22* *(0.88)*	*-0.01* *(-1.66)*	85	0.39	1.19
	Machinery and equipment n.e.c. (29)	-2.00 (-5.16)	0.94 (11.70)	0.78 (5.91)	*-0.24* *(-1.79)*	0.03 (2.74)	100	0.68	1.10

Table A.3 (continued)

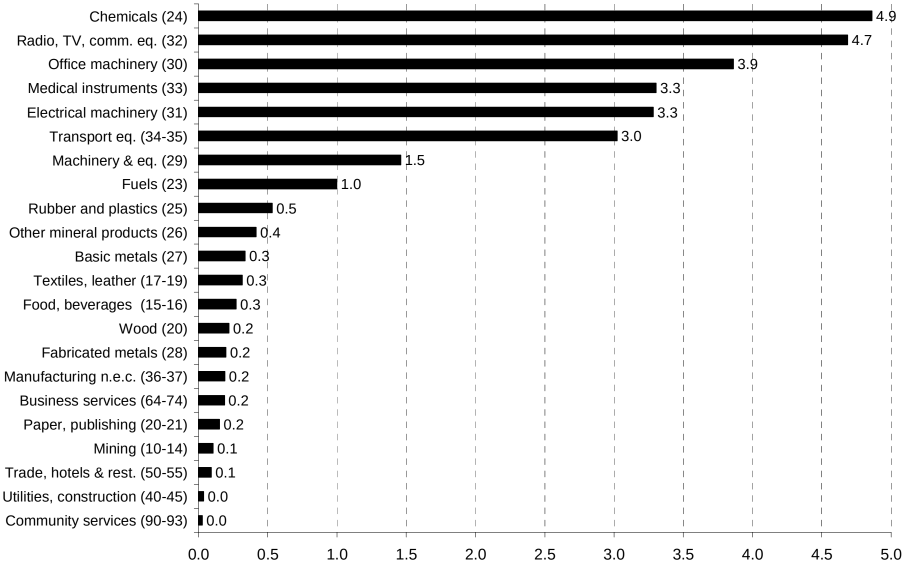
***Y* = inward R&D in relation to GDP**	Office, accounting and computing machinery (30)	-4.65 (-4.32)	1.34 (8.48)	0.61 (5.80)	0.98 (3.13)	-0.08 (-2.15)	57	0.74	1.45
	Electrical machinery and apparatus n.e.c. (31)	-3.08 (-8.10)	1.27 (11.14)	0.64 (8.60)	0.65 (8.44)	-0.05 (-3.96)	79	0.87	2.43
	Radio, TV and communication equipment (32)	*-2.91* *(-1.99)*	0.93 (4.02)	*0.57* *(1.97)*	*0.27* *(0.36)*	*-0.01* *(-0.30)*	72	0.46	0.93
	Medical, precision and optical instruments (33)	*-1.17* *(-1.53)*	1.37 (8.22)	0.91 (4.38)	*0.11* *(0.36)*	-0.04 (-1.99)	91	0.63	0.66
	Transport equipment (34-35)	-1.37 (-2.06)	1.32 (22.66)	0.69 (2.11)	*-0.21* *(-0.78)*	*0.02* *(1.08)*	85	0.87	0.71
	Furniture, recycling and manufacturing n.e.c. (36-37)	*-0.07* *(-0.04)*	1.11 (3.19)	0.94 (1.93)	-1.03 (-2.19)	*0.03* *(0.95)*	78	0.25	1.13
	Electricity, gas, water supply and construction (40-41, 45)	3.28 (2.51)	1.01 (10.39)	1.47 (11.75)	-0.76 (-3.23)	-0.05 (-2.05)	56	0.85	1.87
	Trade, repair, hotels and restaurants (50-55)	*-0.02* *(-0.02)*	0.52 (5.09)	1.17 (6.71)	*-0.33* *(-1.76)*	*0.03* *(1.15)*	51	0.69	0.84
	Finance, insurance, real estate and other business services (65-74)	*0.34* *(0.06)*	0.69 (4.18)	*0.40* *(0.72)*	*-1.49* *(-0.98)*	*0.08* *(1.12)*	52	0.43	0.67
	Community, social and personal services (75-99)	-18.87 (-3.60)	*-0.41* *(-1.54)*	0.28 (4.15)	*1.16* *(0.57)*	0.38 (4.59)	43	0.46	1.91

Remarks: variables that have an insignificant effect on the dependent variable are printed in *italics* (based on a 95% confidence interval) and t-values are shown between brackets. All estimations were conducted using White cross-section standard errors & covariance (d.f. corrected).

In many industries, the effect of human capital on our dependent variable is insignificant and in some industries (e.g. *food, beverages and tobacco*; *manufacturing n.e.c.*; and *electricity, gas, water supply and construction*) there is even a counterintuitive significant *negative* impact on the inward R&D investments of foreign affiliates. Conversely, human capital demonstrates a significant positive effect on the inward R&D intensity in estimates for the industries *mining and quarrying*; *coke, refined petroleum and nuclear fuel*; *chemicals and chemical products*; *office, accounting and computing machinery*, *electrical machinery and apparatus n.e.c.* With the exception of mining and quarrying, these are all industries with a high inward R&D intensity (see Figure A.1).

In addition, industries that show a negative impact of the human capital variable demonstrate a low rate of inward R&D intensity (again Figure A.1). Another possibility of the mixed results with respect to the human capital variable is that our variable (i.e. the share of highly skilled workers) is not adequate to fully cover the importance of human capital as a location factor of foreign R&D. In the time series analysis in this paper (see Table 7.6), alternatively we use a broader indicator of human capital, being the average duration of education of the working-age population.

Figure A.1 R&D expenditure of foreign affiliates as a percentage of value added, unweighted average over countries and years



Remarks: the industry descriptions in Figure A.1 are abbreviated. The ISIC (Rev. 3) codes in brackets correspond with the ISIC codes in Table A.3, which can be used to derive the full description of each industry.

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CHAPTER 8

Internationalisation of R&D within small, open economies – The Dutch case

8.1 INTRODUCTION

Knowledge and innovation are two of the most important determinants of productivity growth and economic wealth (Baumol, 2002). The significance of innovation as a source for future economic growth is also recognised by European political leaders. At the beginning of the new millennium they formulated two main innovation goals: the Lisbon agenda and the Barcelona target. The Lisbon agenda states that Europe must transform itself into the most competitive knowledge-based economy worldwide by 2010 (European Commission, 2002). The Barcelona target declares that the level of investment in research and development (R&D) in Europe must rise towards 3% of gross domestic product (GDP), and that the private sector must account for two-thirds of this new R&D investment (European Council, 2002). Whereas it is debatable whether these goals are realistic, they do convey a powerful message. Compared to the US, productivity growth in Europe is lagging, and closing this gap requires a serious innovative effort.

One striking phenomenon within this context is the increasing internationalisation of R&D activities.[145] During the second half of the 1990s the internationalisation of business R&D has grown markedly, making it a topic of growing interest to the business community, academics and policymakers alike. Many countries are struggling with the question how to deal with this trend of globalising R&D. The general feeling is that this internationalisation trend of R&D poses a threat since domestic firms can relocate their laboratories and research facilities abroad. In this chapter we do not deny this potential danger. However, in our view it reflects a one-sided perspective that ignores a more positive outlook on the same phenomenon. Countries may also benefit from the establishment of foreign R&D units within their borders. In other words, we argue that this trend could provide attractive opportunities as well, something which in view of the internationalisation trend of R&D should clearly be taken into consideration when

[145] See for instance, Granstrand (1999), Patel and Vega (1999) and other contributions to the special issue of Research Policy.

developing policy measures. Moreover, we contend that globalising R&D, with its associated threats and opportunities, is especially relevant for countries like the Netherlands, Belgium, Denmark, Sweden and Ireland, which are characterised by relatively small and open economies. We expect countries such as these to be more affected by the internationalisation trend than large(r) and less open economies, such as Japan and the US.

The aim of this chapter is to obtain a better understanding of this 'dual face' of internationalisation of R&D. By doing this we can provide a helping hand to those policymakers that deal with this challenging trend. Our analysis is particularly from a Dutch perspective. We also take a look at several other countries as well, which enables us to make some relevant comparisons.

This chapter is structured as follows. In Section 8.2 we start with some theoretical notions when we elaborate on the importance of R&D and R&D spillovers as a source of economic growth. Section 8.3 discusses the phenomenon of internationalisation of R&D and studies its impact on private R&D intensity. As already mentioned, the focus here will be on the effects on the Dutch economy in particular and on small and open economies in general. We discuss the location determinants of R&D investments and how they affect internationalisation in Section 8.4. Section 8.5 analyses and compares the R&D investment climate of the Netherlands, the EU15 and three additional small, open economies (i.e. Sweden, Ireland and Slovenia). Finally, in Section 8.6 we make some concluding remarks and discuss some recent Dutch policy measures with potential relevance for other small, open economies.

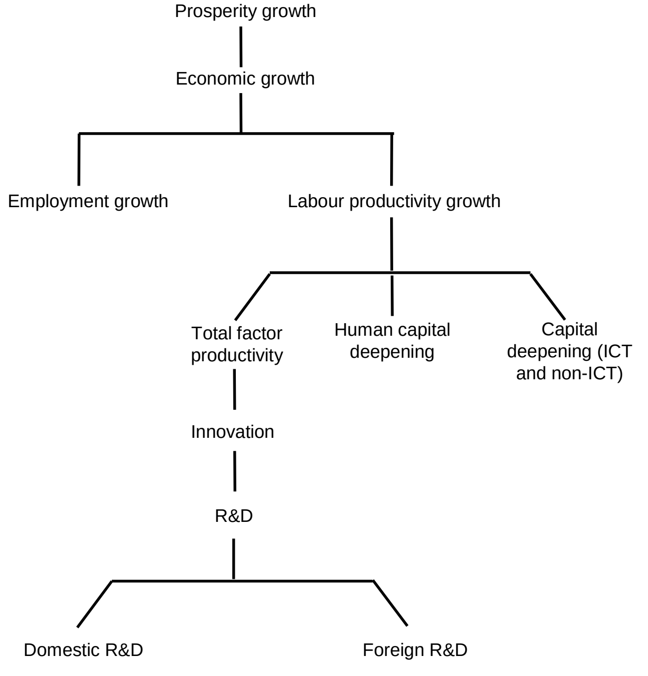
8.2 GROWTH, R&D INVESTMENTS AND THE GEOGRAPHY OF SPILLOVERS

R&D and economic growth

The neoclassical growth theory describes how labour and capital combine to produce output. In the 1950s, researchers like Abramovitz (1956), Kendrick (1961) and Solow (1956) used the framework provided by this theory to analyse economic growth in the US. In these so-called growth accounting exercises, it was found that a large part of growth of per capita income could not be explained by a mere increase in the amount of capital available per worker, nor by the relative number of people participating in the production process. An unexplained residual – named total factor productivity – remained when trying to attribute economic growth to its sources (see, for instance, Griliches, 1996). This residual inspired numerous researchers to extend the neoclassical model in search for yet other sources of growth of per capita GDP.

Since the early exploratory work of Abramovitz and others, consensus has emerged as to the main sources of economic growth. Besides traditional increases in the amount of capital available per worker (capital deepening), improvements in the quality of labour as well as innovation are generally considered to be the leading drivers of productivity growth and thus economic growth.[146]

Figure 8.1 Sources of economic growth



Based on the framework depicted in Figure 8.1, Donselaar *et al.*, (2003) investigated the sources of labour productivity growth in the Netherlands over the period 1990-2000 (see Chapter 3 of this dissertation). The aim in this study was to determine the extent to which the growth in labour productivity could be attributed to each of its three distinct sources: capital deepening, labour quality improvements (human capital deepening) and innovation. Their results indicate that traditional capital deepening accounts for 47% of the observed growth, increases in the amount of human capital per worker explain 13%, and innovation is responsible for the remaining 40% of labour productivity growth. Similar studies for a set of countries sketch more or less the same picture in terms of the importance of R&D and innovation for growth (e.g. Coe and Helpman, 1995, 2008; Oliner and Sichel, 2000; Scarpetta *et al.*, 2000).

[146] The quality of labour improves through schooling and training. Educational investments increase the amount of human capital available for production. Similarly, innovative activities, e.g. businesses investing in R&D, lead to the creation of new knowledge, which in turn increases overall productivity.

Although these growth accounting exercises are quite insightful, they still fail to fully explain the actual growth process. There are three reasons for this. First, the formal separation of the sources of economic growth leaves aside important interactions between the various factors (see, for instance, Nelson, 1964; Maddison, 1987; and Scott, 1989). To illustrate: there is a significant interaction between innovation and capital investments. Performing R&D provides companies with new business opportunities. These opportunities in turn induce capital investments, for example in new production facilities.[147] While both R&D and capital investments increase labour productivity, it is still difficult to separate their distinct contributions. Some observed labour productivity growth might wrongly be attributed to capital investments (and vice versa). The explanatory power of growth accounting exercises is limited further by the existence of a feedback mechanism from investment in capital to R&D. By increasing labour productivity, and ultimately national income, the accumulation of capital increases the market size. In turn, a large potential market stimulates the conduct of R&D in the form of demand pull (cf. Schmookler, 1966; Sokoloff, 1988; and Ades and Glaeser, 1999). Because growth accounting reveals nothing about the extent and nature of the interaction between, inter alia, R&D investments and capital accumulation, the actual process of growth remains a black box.

An additional problem relates to measuring innovation. Innovation entails far more than just the R&D associated with research laboratories. Innovation does not only come in the form of new or improved products and production processes, but also as improvements in business methods, such as logistical processes, customer management and new services. The reason for using data on R&D investments is simple: long time series data on innovation are lacking. The drawback in this respect, however, is that some innovative activities and their contribution to growth are missed out on. Finally, abstract growth accounting exercises ignore the relevance of the so-called 'national innovation system'. R&D investments are only inputs to the innovation process. It is the whole system of institutions (public and private), legislation, interaction between R&D actors, the industry structure and demand factors that profoundly shape the innovation process and its associated output (see, for instance, Nelson, 1993). In other words, the quality of a country's innovation system is a major determinant of its R&D investment climate.

The role of proximity in R&D spillovers

Another deficiency of neoclassical growth models (e.g. Solow, 1956) is that knowledge is not created but is somehow available like a '*deus ex machina*'. Recently, new or endogenous growth theory has addressed this weakness of the old exogenous neoclassical growth theory by endogenising the creation of knowledge.[148] A marked feature of endogenous growth models is that knowledge is (at least partly) nonrivalrous and non-excludable. Knowledge can spill over to

[147] Aoki and Yoshikawa (2002) present an interesting theoretical treatment of this interaction. In their model R&D results in new products (or sectors) and has its impact on growth through the creation of demand. Growth is ultimately caused by the accumulation of capital for the production of goods that enjoy rapidly growing demand.

[148] Excellent overviews of the growth theory in general and new or endogenous growth theory in particular can be found in Aghion and Howitt (1998), Jones (1998) and Romer (2001, Chapter 1-3).

others. According to endogenous growth theory, these spillovers (or externalities) create constant or even increasing social returns from the investment in knowledge, and act as the long-run driving force of economic growth (cf. Romer, 1994).

The assumption regarding the extent of knowledge spillovers of the endogenous growth theory has received a great deal of criticism, both from a theoretical and an empirical perspective (Solow, 1994; Jones, 1995). Moreover, much empirical work has established that the extent of spillovers from R&D is limited by geographical distance. As Feldman and Audretsch (1999, p. 410) note, "new economic knowledge may spill over, but the geographical extent of such knowledge spillovers is bounded" (see also Jaffe *et al*., 1993).[149] The idea is that knowledge created through R&D activities is, at least partly, tacit (cf. Nelson and Winter, 1982). Tacit knowledge, in turn, is the type of knowledge that is 'sticky', i.e. difficult and costly to transfer (Von Hippel, 1994). The result is that the costs of knowledge transfer increase with distance. Hence, the 'stickiness' of knowledge is an important determinant of the location where innovative activities take place (ibidem; Ogawa, 1997). Furthermore, in analysing MNCs' international strategy, Cantwell and Santangelo (2002) find clear indications that multinationals target local geographical areas where they benefit from spillovers and externalities.

The fact that proximity matters for the extent of spillovers from R&D activities has farreaching implications. It means that a country cannot simply lean back and wait for R&D spillovers to arrive. It cannot free ride on the efforts of countries at the world technological frontier. *Home-base R&D* is of crucial importance for increasing the domestic knowledge stock and economic growth.[150] In addition, as we will discuss in the next section, foreign R&D investments provide a powerful vehicle for international R&D spillovers.

8.3 INTERNATIONALISATION OF R&D AND THE INTENSITY OF DOMESTIC PRIVATE R&D INVESTMENTS

In this section we look at the impact of internationalisation of R&D on private R&D intensity (private expenditures on R&D as a percentage of GDP) mainly from the perspective of the Dutch economy. We also take a look at the importance of foreign R&D in general and for small, open economies in particular.

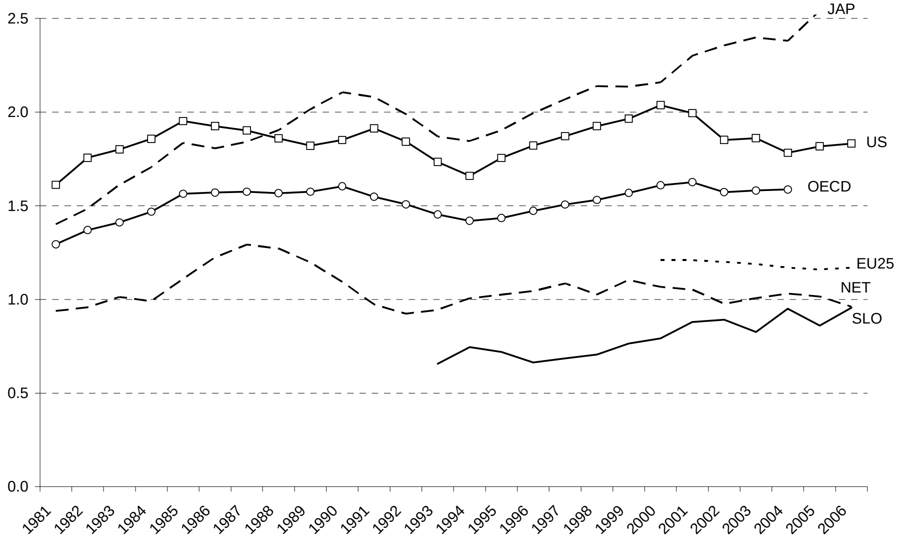
Figure 8.2 presents data on (domestic) private R&D intensity for the Netherlands, Japan, the US, the OECD, the EU25 and Slovenia. This figure shows clearly that the Netherlands (with a private R&D intensity of 0.98% in 2006) is lagging behind the EU25 average (1.12% in 2006)

[149] Nonetheless, spillovers are real and significant; see, for instance, Griliches (1992), Nadiri (1993), and Branstetter (2000a) for overviews of empirical work.

[150] Cohen and Levinthal (1989) emphasize the importance of R&D as a means of absorbing the knowledge created by others.

and, to a larger extent, the OECD average (1.53% in 2004). Strikingly, the Netherlands and Slovenia are almost on the same level in terms of private R&D intensity.

Figure 8.2 Private R&D intensity



Source: Eurostat and OECD Main Science and Technology Indicators, 2006-2.

The main reason why R&D intensity in the Netherlands is lagging behind the OECD average is the Dutch *industry structure* (Erken and Ruiter, 2005; also see Hollanders and Verspagen, 1999; Chapter 5). Compared to other countries, Dutch businesses are mainly active in R&D extensive industries. Calculations by Erken and Ruiter (2005) indicate that in 2001 the industry structure was responsible for 60% of the Dutch R&D lag (0.33 percentage points of 0.54 percentage points in total). The complement of the industry structure effect is called the *intrinsic effect*, which accounts for the remaining 40% of the total lag in private R&D intensity. The negative intrinsic effect of the Netherlands in turn is strongly related to the internationalisation of R&D.

The internationalisation of R&D

Globalising R&D has two directions, outward R&D investments and inward R&D investments. *Outward R&D* refers to the R&D activities performed abroad by home-base multinationals. The general fear is that home-base R&D will increasingly be pulled out of developed countries and be relocated to countries such as China and India in search of low labour costs.[151] In this

[151] See, for instance, Financial Times, *Offshoring trend hits Germany*, 02-02-2005. This article states that Germany is facing an R&D-offshoring trend. R&D activities are located towards Central and East Europe and Asia. In 66% of these cases, the offshoring of R&D concerns support of foreign production facilities.

interpretation, outward R&D clearly concerns the movement of R&D activities *at the expense of* home-based R&D activities. The other side of the internationalisation coin is referred to as *inward R&D* and indicate the influx of R&D or R&D activities of foreign affiliates. This side of the internationalisation process of R&D is often neglected. Nevertheless it does constitute an important pillar of the total private R&D expenditure within countries. The total influence of R&D internationalisation on the private R&D investments in a country is determined by the balance between outward R&D investments (concerning solely the *relocation of R&D*) and inward R&D investments. Below we will discuss both elements separately in more detail.

Outward R&D investment

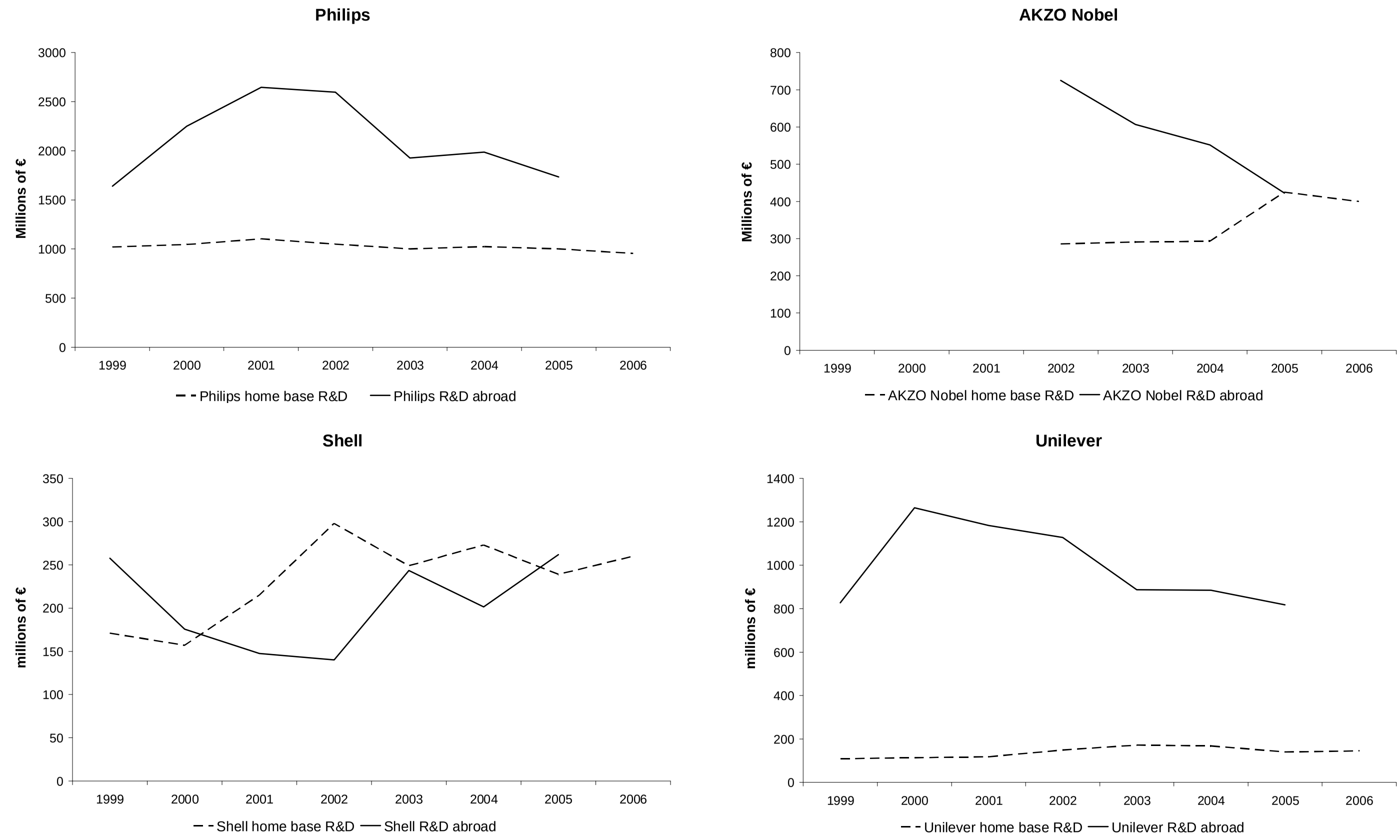
Indigenous R&D firms invest in R&D abroad. If these R&D investments abroad are at the expense of their home-base R&D, then the outward R&D has a negative impact on home-base R&D capacity. Unfortunately, macroeconomic figures on outward R&D investments are only available for a small number of countries, and those figures do not include the Netherlands. By narrowing our focus to the so-called ‘Big Seven’, however, we are still able to provide a detailed analysis of outward R&D investments originating from the Netherlands. The Big Seven comprises the seven largest Dutch R&D companies: Philips, AKZO Nobel, ASML, DSM, Shell, Unilever and Océ.[152] These companies account for roughly 50% of the total business R&D expenditure in the Netherlands.[153] It does not require a great deal of imagination to assume that these same companies also account for a major part of the total outward R&D investment by Dutch companies. The skewed distribution of business R&D expenditure in the Netherlands makes it possible to study the total outward R&D by merely taking a look at the R&D investment behavior of these seven companies.

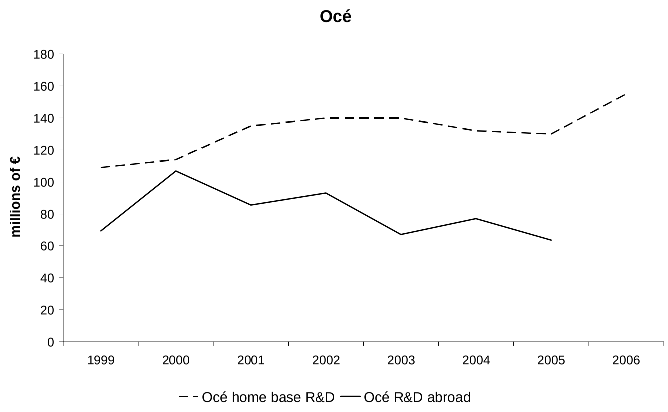
Figure 8.3 shows the home and foreign R&D expenditure of the Big Seven. Moreover, we have added Corus as one of largest R&D investor in the Netherlands following the Big Seven. The figure clearly reveals that over the period 1999-2006 Dutch multinationals have not increased their foreign R&D activities at the expense of their home-base R&D. On the contrary, the majority of the Big Seven has actually scaled down their R&D activities abroad, while maintaining their home-based R&D efforts or increasing them.

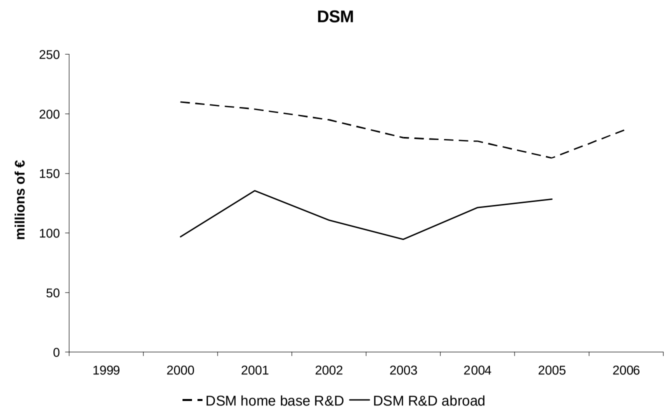
[152] Philips span-off their semi-conductor branch in 2006, which carried on as NXP. Similarly, AKZO Nobel sold their chemical daughter Organon. These organisation changes have not been configured yet in the graphs. A rough estimation states that NXP conducts 400 million of R&D investments in the Netherlands. Philips’ R&D will consequently is downscaled to approximately 675 million.

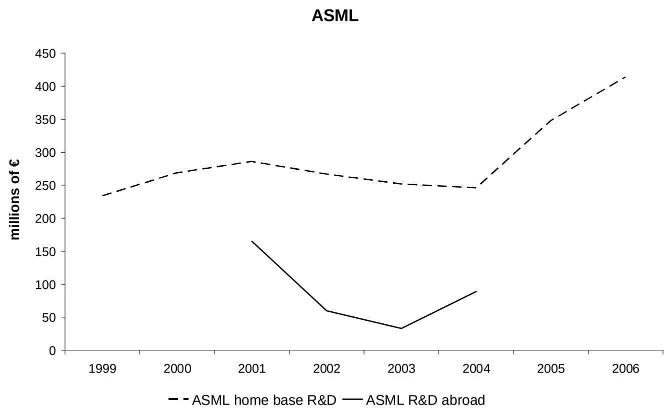
[153] The subsequent smaller group of firms consists of 280 companies which are responsible for 32% of the total Dutch private R&D expenditure. The remaining 18% of total business R&D in the Netherlands is undertaken by some 11,700 businesses (approximately 6,000 in manufacturing and 5,700 in services). The situation in the Netherlands is not exceptional compared to other (small, open) economies. A small number of businesses conduct a significant proportion of total corporate R&D in Sweden (Ericsson, Volvo and Scania), Switzerland (Novartis, Roche and Nestlé) and Finland (Nokia) too.

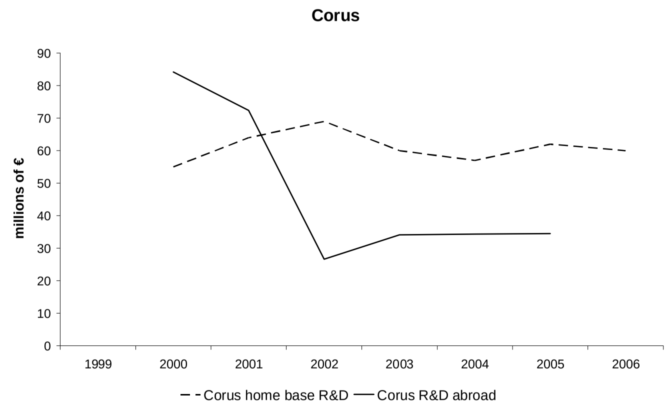
Figure 8.3 R&D expenditure of the Big Seven (including Corus) at the home base and abroad, in millions of euros, 1999-2006











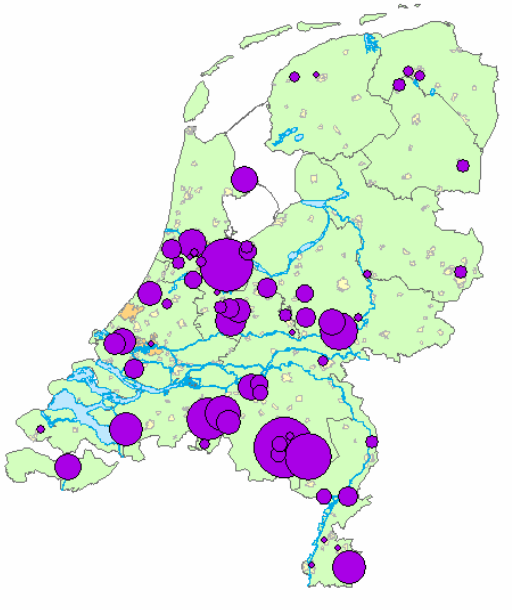
Source: calculations based on data by Technisch Weekblad (http://www.technischweekblad.nl/extra/ Top_40_bedrijfs_r&d_2005.pdf) and the R&D Scoreboard of the British Department for Innovation,. Universities and Skills, http://www.innovation.gov.uk/rd_scoreboard/?p=69.

The observation that R&D activities abroad by Dutch multinationals were not at the expense of R&D activities at the home base is consistent with earlier observations over the period 1977-2000 by Cornet and Rensman (2001). We conclude that outward R&D in the Netherland does not have a negative impact on the Dutch corporate R&D intensity, or at least not up till now.

Inward R&D investment

Commissioned by the Dutch government, Buck Consultants International (2004) examined the number of foreign R&D affiliates active in the Netherlands. They identified 76 affiliates conducting substantial R&D activities and hosting 4,600 R&D employees in total. More than half (41) of these affiliates represent so-called 'incorporated' R&D units, which means that they are linked to other existing production processes of the parent company, such as manufacturing or distribution activities. The remaining 35 R&D units encompass stand-alone R&D units. Figure 8.4 illustrates the geographical distribution of the 76 foreign R&D affiliates in the Netherlands. In particular, these units are concentrated around Schiphol Airport (Amsterdam) and Eindhoven.

Figuur 8.4 Geographical distribution of foreign R&D affiliates in the Netherlands (2004)



Source: Erken *et al.* (2004) based on research by Buck Consultants International (2004). Every mark on the map represents a foreign R&D affiliate (3 digit ZIP code level). The size of each mark illustrates the size of the R&D laboratory, measured by the number of R&D employees (smallest mark = 5 employees; largest mark = 500 employees).

Table 8.1 puts the inward R&D position of the Netherlands in perspective. The table shows that one-fourth of total private R&D in the Netherlands – over the period 1995-2004 – is conducted by foreign affiliates. More in general, the figures illustrate that the contribution of foreign R&D investment to the total private R&D investment (domestic R&D and foreign R&D) is not negligible. Foreign firms in Ireland account for almost 67% of the total private R&D expenditure. At the other end of the spectrum, foreign companies in Japan conduct only 3% of all business R&D. Overall, foreign R&D investments make a substantial contribution to private R&D intensity (almost one-fourth on average in the EU15).

Table 8.1 Contribution of foreign R&D investments to domestic private R&D intensity, contribution in percentage points, averages over 1995-2004

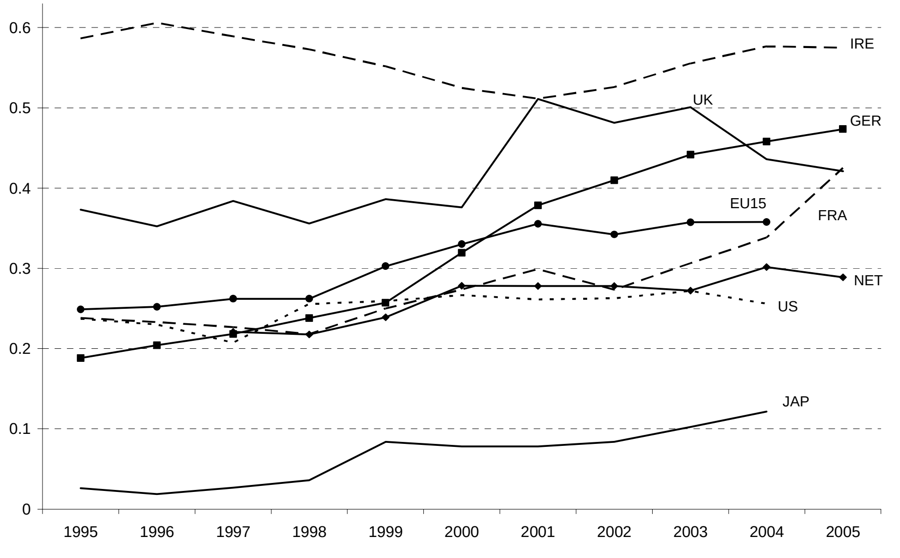
	Corporate R&D/ GDP (%)	Inward R&D/ GDP (%)	Inward R&D/private R&D (%)
Ireland	0.84	0.56	66.8
Sweden	2.81	1.04	36.1
Czech Republic	0.71	0.26	35.5
UK	1.23	0.42	35.2
Canada	1.10	0.34	31.2
Spain	0.48	0.14	30.1
Italy	0.53	0.15	28.2
Portugal	0.27	0.06	26.2
The Netherlands	1.06	0.26	25.0
France	1.40	0.27	19.4
Germany	1.63	0.31	18.8
Finland	2.10	0.31	14.0
US	2.00	0.25	13.3
Poland	0.22	0.02	10.7
Japan	2.30	0.07	2.9
EU15	**1.18**	**0.31***	**24.4***
OECD	**1.55**	**0.24****	**14.7****

Source: calculations of the Dutch Ministry of Economic Affairs, based on OECD AFA database, OECD Economic Outlook, no. 82 and OECD Main Science and Technology Indicators. * Weighted average for: Finland, France, Ireland, Italy, Netherland, Portugal, Spain, Sweden and the UK. ** Weighted average for: Canada, the Czech Republic, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Poland, Portugal, Spain, Swedenm the UK and the US.

Besides a substantial *direct* contribution of foreign R&D investments to total business R&D, foreign R&D investments also have two *indirect* benefits for countries. First of all, these investments function as a transmission channel for international knowledge spillovers (see, for instance, Branstetter, 2000b and Keller and Yeapl, 2003; see also the discussion on the importance of proximity for R&D spillovers in the previous section). In other words, foreign knowledge intensive businesses fulfil a bridging function between a country's own innovation system and knowledge developed abroad. Part of the technology within the foreign affiliate situated in a certain country flows to local suppliers in that country, to local personnel employed by the affiliate, and to local knowledge institutes co-operating with the foreign technological affiliate. There are indications that the local knowledge spillovers of foreign R&D activities in a country are as high as the spillovers of native firms (e.g. Jaffe *et al.*, 1993).

Secondly, foreign R&D enhances competition within a country, forcing resident firms to reduce their X-inefficiencies and increase innovative activities.[154] Besides reducing X-inefficiencies, the location of R&D within the most important and dynamic markets will lead to higher learning opportunities for these businesses. They can learn from their foreign rivals and absorption of knowledge spillovers is facilitated by geographical proximity (Porter and Sölvell, 1998). Inward R&D investments increase the innovative performance of domestic firms.

Figure 8.5 Foreign R&D investments as a percentage of GDP, 1995-2005



Source: calculations of the Ministry of Economic Affairs based on the OECD AFA database, the OECD Economic Outlook database no. 82 and the OECD Main Science and Technology Indicators.

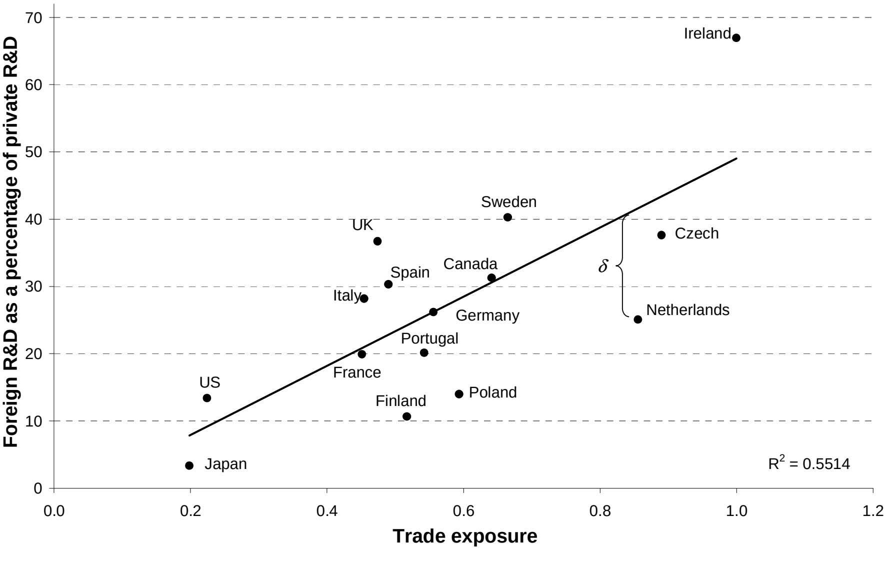
[154] Leibenstein (1966) defines the term X-inefficiency as the difference between how a business could potentially utilize its resources versus actual utilization. He finds that the majority of X-inefficiencies arises from poor motivation by business management, and that this is probably linked to market structure and the extent to which businesses face competitors on their markets.

Figure 8.5 depicts foreign R&D investments as a percentage of value added over the period 1995-2004 for a small selection of countries. In 2004 Sweden (1.26%, not visible in graph), Ireland (0.58%), Germany (0.46%) and the UK (0.44%) attracted the largest amounts of foreign direct investments in R&D as a percentage of GDP. Japan (0.12%), Poland (0.02%, not visible in graph) and Portugal (0.08%, not visible in graph) attracted the least foreign R&D investment expressed as a percentage of GDP. Inward R&D investments in the Netherlands are about average, typically between 0.2% and 0.3% of GDP. The Czech Republic, Sweden, Germany and Finland have experienced significant increases in the R&D investments of foreign enterprises. Inward R&D has increased slightly over the years in the UK, Japan, the Netherlands and France. R&D in Canada, Spain, Ireland and the US remained quite stable.

The importance of foreign R&D investment in small, open economies

We hypothesize that in small, open economies inward R&D investment is more important than in large, closed economies. A well-developed theoretical notion is that openness to global trade is more important for small economies than large ones. The idea is that businesses originating from small countries need to overcome the disadvantage of a small home market by operating on a global scale.

Figure 8.6 Correlation between inward R&D investments and openness of the economy, 1997-2004



Source: calculations by the Dutch Ministry of Economic Affairs based on the AFA database and Main Science and Technology Indicators and OECD Economic Outlook, no. 82.

Subsequent empirical work has confirmed that small economies are more open.[155] Compared to closed economies, open economies are more tuned in to the global market for goods and production factors. Hence, we expect the share of foreign R&D in total R&D investments to be higher in (small) open economies than in (large) closed economies. Interestingly enough, Figure 8.6 shows a positive correlation between inward R&D investments (as a percentage of the total R&D investments in an economy) and the openness of an economy (i.e. trade exposure (Bassanini *et al.*, 2001, p. 25)), giving credibility to our hypothesis. An interesting additional feature of Figure 8.5 is that when adjusted for the openness of the economy, the Netherlands seems to suffer a large *negative* foreign R&D investment gap (marked δ in Figure 8.6).

Erken and Ruiter (2005, see Chapter 5 of this thesis as well) confirm the existence of this foreign R&D investment gap. The authors use the results of an econometric analysis to calculate the magnitude of this gap and find that it is largely responsible for the negative *intrinsic effect* in the Netherlands. Compared to other countries, the share of foreign R&D in the total R&D in the Netherlands is at a similarly low level as in Japan, Finland and Poland. The opposite holds true for Ireland and Sweden. Considering the openness of the Irish and Swedish economy, they attract a relatively high share of inward R&D.

8.4 LOCATION DETERMINANTS OF R&D INVESTMENTS

The previous section has presented a quantitative approach to the internationalisation trend of R&D with a focus on the Netherlands and small, open economies in general. By contrast, in this section we will take a more qualitative approach to the phenomenon of globalising R&D. At the heart of this discussion are the motives of businesses for investing in R&D abroad and the factors that determine the R&D investment climate and consequently the actual location of R&D activities. In the light of the ‘dual face’ of globalising R&D it is interesting to note beforehand that the location factors that make a country an attractive host for foreign R&D investments are the same location factors that might prevent domestic companies from relocating their R&D elsewhere.

Motives for new R&D locations

In the literature a wide array of motives for businesses to invest in R&D abroad have been established.[156] Le Bas and Sierra (2002) and Le Bas and Patel (2007) argue that businesses follow (roughly) two strategies when locating their R&D activities (cf. Kuemmerle, 1997 and 1999; see also OECD, 1998):

[155] For interesting theoretical and empirical work on the relation between country size and openness, see Murphy *et al*., (1989), Alesina and Wacziarg (1998) and Ades and Glaeser (1999).

[156] See Niosi (1999) for an overview and Chapter 7 of this dissertation.

1. Home-base exploiting strategy (HBE): R&D is undertaken centrally at the home base and local R&D activities are started up in response to the necessity of adapting to local market conditions. These R&D units thus support centralised R&D at the home base.
2. Home-base augmenting strategy (HBA): R&D activities are developed at locations where there is obvious strength in the same area of technology. These new local activities are complementary to the central R&D activities and focus on expanding the firm's knowledge base.

They also find that the size of the home country plays a role in shaping the internationalisation of R&D strategies. Companies from small (and open) economies, such as the Netherlands, use internationalisation of R&D extensively to augment their home base. Finally, Le Bas and Sierra (2002) found that the importance of HBA strategy grew during the 1990s (see also Gassmann and Von Zedtwitz, 1999; Serapio and Dalton, 1999). Kuemmerle (1999) observes that the two strategies are associated with several specific location characteristics for R&D investments. In case of an internationalisation strategy aimed at exploiting home-base advantages and capabilities (HBE), the R&D units were established in the vicinity of manufacturing and marketing facilities. R&D that has been located from a HBE strategy is also referred to as 'adaptive' R&D. The idea is that these subsidiaries are set up abroad with the purpose of adapting centrally created products and processes to meet local market circumstances (see, for instance, Fors 1998). R&D units established with the aim of augmenting the knowledge base of a business (HBA) are generally located nearby universities and other knowledge institutes. The R&D activities from HBA subsidiaries are sometimes referred to as 'access to science' R&D (Von Zedtwitz and Gassmann, 2002).

Factors that determine the R&D investment climate

A quite clear picture emerges from the literature regarding desirable local conditions for the establishment of R&D activities. Frequently mentioned location determinants are political factors (e.g. Håkanson and Nobel, 1993), the availability of skilled human resources (e.g. Florida, 1997), market size (e.g. Kumar, 2001) and the existence of sector-specific knowledge spillovers (e.g. Cantwell and Piscitello, 2002; European Commission, 2003, p. 19-21).[157] In addition, framework conditions appear to be influential factors in companies' decision regarding a location for its R&D activities. Some of these framework conditions are international accessibility, flexible licensing procedures, a well-functioning IPR (Intellectual Property Rights) regime, national security, a sound physical infrastructure, the availability of natural resources (sea water, clean air, fossil fuels) and the existence of suppliers of high-quality materials (see, for instance, Brockhoff, 1998). Cost aspects of R&D seem to be of lesser importance to foreign firms than quality aspects of a country's innovation climate (Edler *et al*., 2001).

[157] Note that the availability of skilled human resources (Florida 1997) is mostly associated with the HBA strategy of internationalisation of R&D and market size (Kumar 2001) with the HBE strategy of internationalisation of R&D.

Table 8.2 Location factors by their rank of importance

1.	Quality and availability of human resources
2.	International accessibility
3.	Quality of knowledge institutes
4.	Private R&D capital
5.	Value added of foreign firms
6.	Knowledge transfer between firms and universities
7.	Capacity and quality of ICT/telecom infrastructure
8.	R&D stimulation by the government
9.	Costs of R&D personnel
10.	Quality of life
11.	Taxation
12.	Regulation and legislation
13.	Entrepreneurial activity which fosters innovation

Source: Erken *et al*., (2004), see also Chapter 7 of this dissertation.

Generally, the above-mentioned studies have analysed the determinants of R&D location from a company-level perspective. Recently, R&D location factors have also been studied at the macro level. Doh *et al.* (2005) attempt to explain inward foreign R&D from macro factors such as GDP, the low level of corruption and the telecommunications infrastructure. They find that the quality of the local innovation system is an important location factor. Their results indicate that almost 70% of the observed variation in foreign R&D intensity (inward R&D as a percentage of GDP) can be explained by economic variables (total GDP, GDP per capita) and scientific output (the average number of scientific articles published annually). Based on a combination of macro-level data and company-level data, Erken *et al*. (2004) provide evidence for a ranking of the top five location determinants of R&D: (1) quality and availability of human resources, (2) international accessibility, (3) quality of knowledge institutes, (4) the stock of private R&D capital and (5) value added of foreign firms. Table 8.2, taken from Erken *et al*. (2004), shows various R&D location determinants ranked by their importance (see also Buck Consultants International, 2004 and Chapter 7 of this thesis).

8.5 BENCHMARKING THE R&D INVESTMENT CLIMATE

In the previous section we identified numerous determinants underlying the location of foreign direct R&D investments, as well as the internationalisation process of R&D in general. In this section we make a comparative analysis of the R&D investment climate between the Netherlands and the EU15, and the Netherlands and other small, open economies.

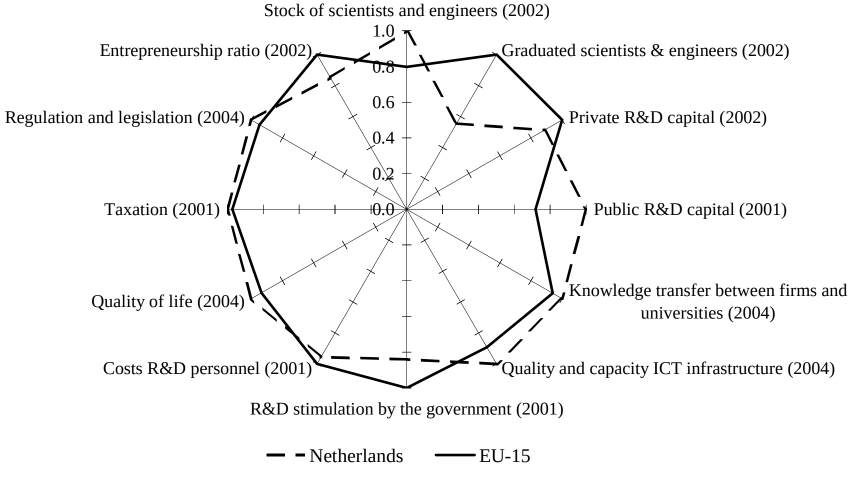
Methodology and data

To benchmark the R&D investment climate between countries we use the same methodology as used in Erken *et al*., (2004). We gather data on the identified location factors of R&D (see Table 8.2), normalise them, and present them in so-called spider diagrams (see Figures 8.7 to Figure 8.10).[158] The country that has the best score on a certain location factor is given a score of 1, and the scores of other countries are shown as a ratio of this score. The importance of the location factors for R&D is shown clockwise in the diagrams. Thus, in our selection of indicators the stock of scientists and engineers is the most important location factor for R&D and the level of innovative entrepreneurship is the least important one. The year of observation is shown in brackets.

The Netherlands vis-à-vis the EU15

In Figure 8.7 the R&D investment climate in the Netherlands is compared with that of the EU15. Overall, the Netherlands is on par with the EU15 in terms of the attractiveness of its R&D investment climate. This probably explains why the difference in business R&D intensity between the Netherlands and the EU15 is small (see Figure 8.2).

Figure 8.7 Benchmark of R&D investment: the Netherlands versus the EU15



[158] Data problems prevent us from using several location factors in the benchmark analysis. Three important location factors that could not be included are: (1) *international accessibility*, (2) *proximity of lead users/strategic partners* and, on occasion, (3) *value added of foreign affiliates*. We have used 'hard' data from the OECD (OLIS) and Eurostat database where possible. On some location factors, however, hard data is unavailable and 'softer' data has been used from alternative sources, such as IMD's World Competitiveness Yearbook. The annex of this chapter gives an overview of the sources used in the benchmark analysis.

Most noteworthy here is the score of the Netherlands on the leading location factor, i.e. the availability of highly skilled human resources. Although the Dutch R&D investment climate is quite favourable in terms of the stock of available skilled R&D personnel, the share of *graduates in science and engineering* (per 1,000 inhabitants aged 20-29) is a reason for concern. The Netherlands ranks well below average on this location factor. In the future, the low influx of newly graduated scientists and engineers could have a strong negative effect on the attractiveness of the Netherlands as a location for R&D.

Some interesting conclusions can be drawn from the benchmark analysis presented above. The most obvious being that the attractiveness of the Dutch R&D investment climate is on par with the EU15 average. This average score on R&D investment climate corresponds with the success the Netherlands has in attracting foreign direct investment in R&D. As Figure 8.5 in Section 8.3 shows, inward R&D in the Netherlands as a percentage of value added is about, or perhaps slightly below, average as well. The Netherlands seems to cope with the internationalisation trend of R&D just as well as other countries; what more can we expect?

However, the international position of the Netherlands changes quite drastically when the openness of the Dutch economy is taken into account. We have postulated that in (small) open economies the contribution of inward R&D to total private R&D intensity is generally much larger than in (large) closed economies. Figure 8.6 subsequently shows that the Netherlands actually attracts far less foreign R&D then might be expected on the grounds of the openness of the Dutch economy (see also Erken and Ruiter, 2005; Chapter 5 of this dissertation). These observations contain an important suggestion for improving future benchmark analyses of the R&D investment climate with regard to the attractiveness for inward R&D investments. The idea of benchmarking is that countries can learn by comparing themselves to their international peers. The usual criterion for reference countries is that they are in the same stage of economic development. However, since size and openness seem to matter when it comes to attracting foreign R&D investments, these factors need to be taken into account as well when using benchmark analyses in light of R&D internationalisation. In this case, international peers should not solely be selected based on GDP per capita, but also based on country size and the openness to foreign trade. For the Netherlands, the appropriate point of reference for this type of benchmark analysis is not the EU15 as a whole, but rather small, open economies. In order to learn from other countries, a small, open economy like the Netherlands should compare the quality of its R&D investment climate predominantly with other small, open economies; especially those with a *positive* foreign R&D investment gap.

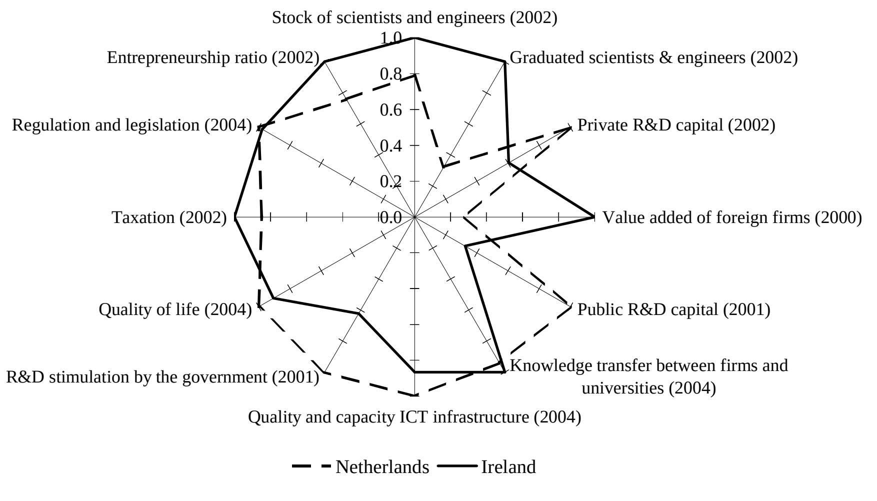
The Netherlands vis-à-vis Ireland and Sweden

To follow up on our proposed improvements to benchmarking the R&D investment climate within the context of globalising R&D, Figures 8.8 and 8.9 draw a comparison between the Netherlands on the one hand and between Sweden and Ireland on the other hand. Sweden and Ireland are both small, open economies and, as Figure 8.6 shows, both exhibit a positive foreign

R&D investment gap. The improved benchmark analyses give rise to some interesting observations. They show that Ireland and Sweden are both attractive locations for foreign R&D investments, more so than the Netherlands. This confirms the data presented in Table 8.1 and Figure 8.6. Moreover, both Figures 8.8 and 8.9 shed light on the question as to why Sweden and Ireland exhibit a positive foreign R&D investment gap (and the Netherlands a negative gap).

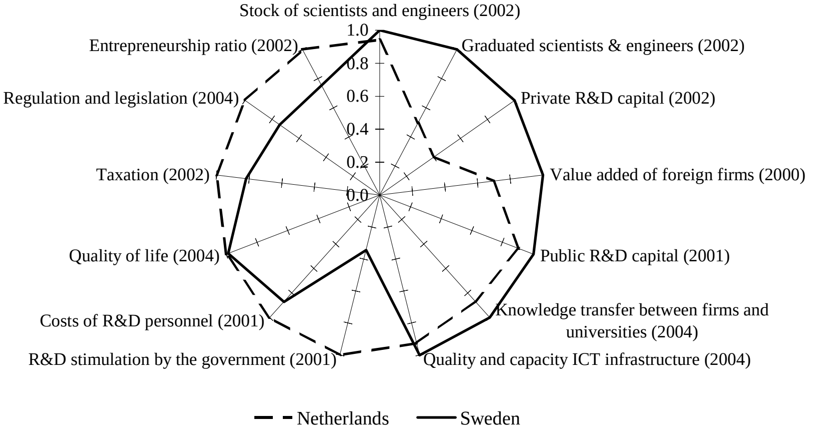
The most important factor underlying Ireland's ability to attract foreign R&D seems to have been the large amount of *other* foreign business activities in Ireland. In 2000, foreign firms were responsible for almost 85% of total value added in the manufacturing industries. Because of its attractive overall business climate, foreign firms often use Ireland as an operating base to serve the European hinterland. Not surprisingly, Ireland is relatively cheap in terms of taxation and has high entrepreneurial dynamics in terms of entrepreneurial activity. The foreign R&D activities in Ireland consist mainly of R&D subsidiaries which are located in Ireland in a home-base exploiting strategy (cf. Kuemmerle, 1997 and 1999; see Section 8.4 of this chapter). These R&D activities are for the most part intertwined with other business activities such as production, distribution and marketing. Thus, foreign R&D in Ireland consists predominantly of adaptive R&D units set up abroad for the purpose of adapting products and processes to meet local market circumstances. On the technology-seeking R&D location determinants, the Dutch R&D investment climate outperforms the Irish. This appears to be of lesser importance, however, simply because the available knowledge base is not the main motive for firms to locate their R&D in Ireland.

Figure 8.8 Benchmark of R&D investment: the Netherlands versus Ireland



In contrast, the case of Sweden relates much more to the knowledge-augmenting strategy. Given its scientific strength, Sweden most likely obtains a large share of foreign R&D by businesses aiming to augment their knowledge base (ibidem). On the most important R&D location factors Sweden consistently outperforms the Netherlands. The attractiveness of the Swedish R&D investment climate vis-à-vis the Dutch climate undoubtedly goes a long way in explaining its lead in attracting foreign R&D.

Figure 8.9 Benchmark of R&D investment: the Netherlands versus Sweden

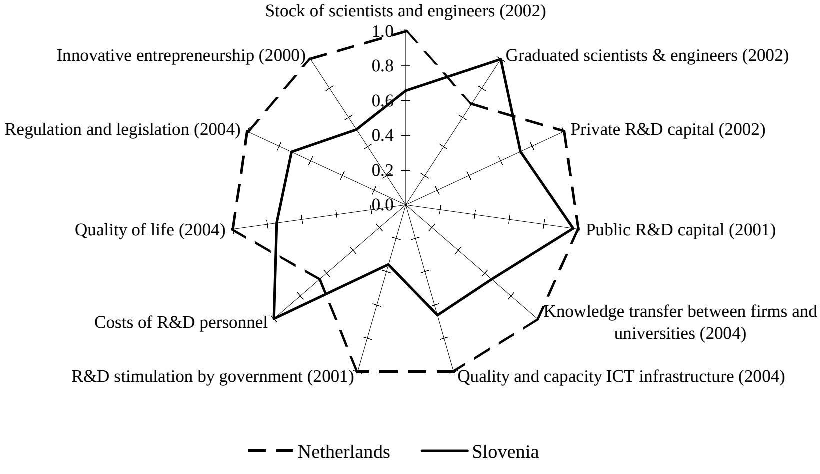


The Netherlands vis-à-vis Slovenia

We conclude our benchmark analyses by comparing the Netherlands to Slovenia as a case of a small, open and *emerging* economy. Figure 8.10 shows a comparison between the R&D investment climate of the Netherlands and that of Slovenia. Apart from R&D labour costs and the number of graduated scientists and engineers, the Netherlands outranks Slovenia on all aspects of the R&D investment climate. Naturally, an important explanation for this difference is that Slovenia is an emerging economy at a comparably low level of economic development.

The low labour costs of R&D personnel in Slovenia (49,000 US$ in 2002 per R&D researcher full-time equivalent (FTE)) compared to the Netherlands (66,000 US$ in 2001 per R&D researcher FTE) does of course reflect a lower productivity of the Slovenian R&D personnel compared to Dutch researchers as well as the immobility of labour. Considering the absolute differences in per capita income between both countries, the low score of the Netherlands vis-à-vis Slovenia on the number of science and engineering graduates may seem odd. However, Eurostat data (structural indicators) on public expenditure on education as a percentage of GDP reveal that in relative terms Slovenia spends more money on human resources than the Netherlands (6.0% in 2002 versus 5.1% in 2002). This observation relates to the threat the low influx of scientists and engineers might have on future Dutch private R&D investments.

Figure 8.10 Benchmark of R&D investment climate: the Netherlands versus Slovenia



8.6 SOME GENERAL CONCLUSIONS AND OPTIONS FOR POLICY

In this section we first draw a number of conclusions. Following these conclusions we consider some recent Dutch policy initiatives that may be of use to policymakers in other small, open economies.

During the second half of the 1990s the internationalisation of business R&D increased considerably. This trend is expected to involve an even bigger challenge to countries with small, open economies – like the Netherlands – than to larger and more autarkic economies. To compensate for their small home-market disadvantage, businesses from these countries need to be much more active on world markets than those from larger countries. Not surprisingly, companies originating from small countries often have established a large network of production facilities, administrative headquarters and sales offices around the world in order to benefit from the business opportunities unavailable in their home market. Hence these multinationals are giving more consideration to (re)locating some of their R&D activities abroad as well. For this reason, the internationalisation trend of business R&D seems to pose a considerable threat to small, open economies, as it contains the risk of losing an important input to innovation and future economic growth. The evidence presented in this chapter does not justify such fear for large-scale relocation of R&D. As far as the Netherlands is concerned, a process of systemic relocation of R&D has not taken place, at least not yet.

The view outlined above reflects an inside-out focus and dominates the (policy) discussion in the Netherlands as much as it does anywhere else. In this view the internationalisation of R&D is seen solely as a threat and the key concern is outward R&D: how much R&D is relocated from the Dutch home base to foreign subsidiaries. Because of this one-sided view, the other side of R&D internationalisation (inward R&D investment) has not been given adequate attention by politicians and policymakers. In this view the internationalisation of R&D provides substantial opportunities. The key concern then becomes the amount of R&D that is being relocated from foreign shores to the Netherlands.

In our opinion the principal challenge for policymakers is to pay proper attention to both outward and inward R&D. We give two main reasons for this. The first concerns an obvious economic argument which is related to the amount of inward and outward R&D. By balancing the two types of R&D investments, it becomes possible to achieve a neutral net effect: some you win, some you lose. The second reason is one of a strategic nature and reflects a knowledge-based argument. When domestic companies relocate some of their R&D, they tap into new knowledge developed elsewhere. This new knowledge then enters the Dutch innovation system through their R&D activities, abroad as well as at home. In this way the Dutch economy benefits from state-of-the-art knowledge developed around the globe. Likewise, when foreign businesses conduct R&D activities in the Netherlands they bring knowledge from their home base to the Netherlands. Hence, R&D internationalisation can connect a country to two new sources of knowledge. Obviously the opposite is also the case: Dutch businesses transfer knowledge developed at their home base to their foreign subsidiaries to the benefit of other countries. Indeed, like normal trade of goods and services, globalising R&D is not a zero-sum game.

Viewed in this way, the threat for small, open economies may not be as destructive as feared initially. On the contrary, it can provide such economies with a first-mover advantage when compared with larger, more autarkic economies that do not feel this threat to the same extent, or to the same extent already. Therefore, the latter could miss out on these two valuable sources of new knowledge. Given the fact that efficiency in R&D is increasingly about creating and maintaining access to state-of-the-art knowledge around world, this may put large countries at a considerable disadvantage.

However, obtaining such a first-mover advantage requires an excellent home base in order to *keep* as well as *attract* R&D activities. We will discuss three prominent tracks of Dutch policy to strenghten the innovation climate (see Ministry of Economic Affairs (2008) for a complete representation): (1) fostering human capital and research, (2) providing the right framework conditions and (3) enabling strategic innovation areas.

Human capital and research

As mentioned in Section 8.5, the R&D investment climate in the Netherlands is bound to suffer from a shortage in high-skilled personnel, especially scientists and engineers (also see Section 4.4.3 in Chapter 4). In particular, the growth in the number of scientists and engineers is far below the international average. This could have serious negative implications for the R&D investment climate of the country. The government is responding to this threat with its Beta/Engineering Delta Plan, which consists of a package of policy measures to address the pending shortage. The policy objective is to develop a climate in the public knowledge infrastructure which will enable people to develop their skills and encourage them to excel. One way of achieving this is by exposing researchers to national and international competition, thereby strengthening their position in the international scientific community (including European research). In addition, the OECD (2005) recommends more flexible immigration laws to attract top talent from abroad. The introduction of a points system, as in other countries, would be a step in the right direction. Also, Dutch universities should be encouraged to compete more vigorously for foreign science and engineering students and work permit regulations should be relaxed. A more recent initiative is the formation of the Taskforce Technology, Education and Labour Market (in Dutch: Taskforce Technologie, Onderwijs en Arbeidsmarkt (TOA)). This taskforce is asked to provide a solution to the emerging shortages of scientist and engineers in the Netherlands. The method of operation of this taksforce is, however, still insufficiently clear.

Regarding the Dutch public knowledge infrastructure, public-private interaction is another important topic. The Netherlands, and Europe in general, is struggling with a phenomenon that has become known as the ‘European paradox’ (European Commission, 1994) or the ‘knowledge paradox’. Despite the strength of its education and science base, the Netherlands and Europe appear to be inefficient in converting this advantage into technological performance, especially compared to the US. Low rates of valorisation of knowledge is evidenced by the low rate of new and significantly improved product, measured in the Community Innovation Survey (CIS). The insufficient valorisation of knowledge seems mainly due to poor knowledge transfer between publicly financed knowledge institutes and businesses, especially small and medium-sized enterprises. To deal with the knowledge paradox the Dutch government has initiated several policy initiatives. First, by means of so-called *innovation vouchers* the government aims at reducing the gap between SMEs and the knowledge infrastructure. These vouchers enable businesses (SMEs) to purchase knowledge from public knowledge institutes and submit research questions to them. Due to its success, the innovation voucher scheme will be extended from 6000 to 8000 vouchers for the years 2008 to 2010, and will be available to all small and medium-sized businesses. A second important element in bridging the gap between knowledge institutes and industry is to commence incentives for knowledge institutes to focus on research that connects to market needs. Finally, in the longer term, the Dutch Government intends to reform the system of university funding. An important feature will be the periodic redistribution of funds to the best-performing universities and/or university departments.

Framework conditions
Another important aspect of an excellent R&D investment climate are appropriate framework conditions. The Dutch government is making a serious effort to alleviate the burden of bureaucracy (the aim is a reduction of 25%). The use of ICT tools fosters flexibility and lowers legislative burdens. High market dynamics are relevant for creating opportunities for large MNOs to augment their knowledge base nationally by acquiring small-scale radical innovators. In recent years the government substantially improved competition on its markets and will continue to do so, among other things through the deregulation of certain markets. In addition, the Dutch government aims at providing an attractive fiscal climate. Significant improvements have been made in lowering the rate of corporation taxation to 25.5%: a highly competitive level compared European peers. In addition, a 10% profit exemption in income tax for small and medium-sized businesses has been introduced and the Dutch R&D tax credit (WBSO) will be gradually extended, from € 39 million in 2009 to € 115 million in 2011. Finally, businesses need to be accessible (internationally) and require space to operate. This applies not only to foreign companies in search of a location for their production sites or distribution centers, but also applies to their R&D activities. The Netherlands addresses this issue mainly by stimulating investments in its main hubs, Amsterdam Schiphol Airport and the Port of Rotterdam.

Strategic innovation areas
The Netherlands is too small to achieve and maintain excellence in all possible areas. The Dutch Government has therefore decided to make a deliberate choice and concentrate on a number of strategic areas – in science and industry – in which the Netherlands either excels already, or has the potential to excel. The idea is to create sufficient focus and critical mass by linking excellent companies to knowledge institutions. This can lead to high-performance clusters which in turn can induce substantial agglomeration benefits. In this way, the Netherlands could become a powerful magnet to attract knowledge-intensive foreign companies to decide to make R&D investments.

To help realise focus and mass in the Dutch innovation system, the Ministry of Economic Affairs sent a letter to Parliament proposing a radical overhaul of financial instruments (Ministry of Economic Affairs, 2004) in order to increase flexibility and customisation. The new system will have fewer instruments but more coherence, fewer helpdesks but more accessibility and lower acquisition costs and administrative burdens. An accessible and transparent basic package provides entrepreneurs with information and capital. The primary focus is on entrepreneurs that want to innovate, export and/or engage in overseas investments. In addition, a related programme-based package offers possibilities for concentrating innovation resources in a number of fields in which the Netherlands has the capacity to excel. The programme-based package also aims to improve links between science and industry and to sharpen the focus of innovation policy. The selection of technological areas is organised through a bottom-up approach. The idea is to give the market the scope to concentrate on leading areas of innovation; the government will act only as a facilitator by bringing parties together, for example in exploring new fields of research. Eight innovation programmes are up and running or underway: Point-One, Food & Nutrition Delta, Water Technology, High-Tech Automotive Systems, Maritime, Materials, Chemicals/Polymers and Life Sciences & Health (Ministry of Economic Affairs and SenterNovem, 2008). To give an example, the innovation programme Point-One aims at strengthening the leading position of the Dutch high-tech cluster in the field of nanoelectronics and embedded systems (http://www.point-one.nl). In this programme, small and large companies, education and research institutes collaborate closely on the basis of a strategic research agenda. More recently, the Dutch government is encouraging cross-pollination between the economy and society bij setting up innovation agendas on societal issues (Ministry of Economic Affairs, 2008). Firms and knowledge institutions are stimulated to exert their knowledge and technology in tackling social problems, for instance in the field of national health care, the environment, energy supply, security and education. Within the innovation theme 'Water', two project are already initiated: Building with Nature (Ecodynamic Design) and Flood Control 2015. The former will enable companies and knowledge institutes to create new knowledge and design concepts for the sustainable development of coastal, delta and river areas. The purpose of the Flood Control 2015 project is to permanently monitor water barriers in the Netherlands with sensors and electronic equipment: this will result in the immediate detection of any weak links. As a result of this project, IBM has decided to locate a global center of excellence in the field of advanced water management in the Netherlands.[159]

Another illustrative example of how to create focus and mass are the Dutch Leading Technological Institutes, which received the designation of 'good practice' from the OECD (2003). These institutes are mainly virtual and constitute an innovative model for public-private collaboration in a number of selected fields: telematics, food, polymers and metals. Each of these four institutes brings together a number of public research organisations (e.g. universities, national research centers) and industrial partners. The resulting network combines the strengths of the best researchers in the Netherlands, engages them in industrially relevant programmes, and helps co-ordinate research activities in areas of strategic relevance to Dutch society. These Leading Technological Institutes constitute an important part of the innovation programmes.

In combination, the policy initiatives mentioned in this section aim to address the 'dual face' of R&D internationalisation: remaining attractive for established foreign companies and attracting foreign companies to make local investments. In this way the Netherlands can maintain a strong local R&D base that provides sufficient absorptive capacity to benefit from new sources of knowledge scattered around the globe.

[159] See http://www.ibm.com/news/nl (1-2-2008): *IBM vestigt Global Center of Excellence voor waterbeheer in Nederland* [IBM locates Global Center of Excellence in the field of water management in the Netherlands].

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ANNEX 1. Data and constructed indicators used in benchmark analysis (Section 8.5)

Table A.1 Sources used in benchmark of R&D investment climate

Location factors	Sources
Stock of scientists and engineers	Labour Force Survey, Eurostat database
Graduated scientists and engineers	Eurostat Structural Indicators, Eurostat database
Private R&D capital as a % of GDP	OECD Main Science & Technology Indicators and OECD Economic Outlook
Public R&D capital as a % of GDP	OECD Main Science & Technology Indicators and OECD Economic Outlook
Value added of foreign firms as a % of value added, total manufacturing	OECD AFA database and OECD STAN database
Knowledge transfer between firms and universities	IMD World Competitiveness Yearbook 2004
Quality and capacity ICT/telecom infrastructure	EIU (e-readiness rankings)
R&D stimulation by government	OECD beta index, OECD Main Science & Technology Indicators
Labour costs of R&D personnel	OECD Main Science & Technology Indicators
Quality of life	IMD World Competitiveness Yearbook 2004
Taxation	OECD Taxation Statistics
Regulation and legislation	IMD World Competitiveness Yearbook 2004
Entrepreneurship ratio and Innovative entrepreneurship	EIM Compendia, Eurostat database (CIS 3)

Construction of some indicators

- The stock of *R&D capital* is calculated by the accumulation of R&D expenditure from the past, while taking depreciation of the existing stock of R&D capital due to knowledge obsolescence into account. With regard to the depreciation of knowledge, a fixed depreciation rate of 15% is used. Griliches (2000, p. 54) refers to this 15% as the *"'conventional' 15 percent figure for the depreciation of R&D capital"*. Data on R&D expenditure are taken from the OECD Main Science and Technology Indicators, 2004-2.
- *Regulation and legislation* is based on an unweighted average of four indicators from the IMD World Competitiveness Yearbook: (i) labour regulation, (ii) competition regulation, (iii) legal regulation of financial institutions, and (iv) environmental laws.
- *Labour costs of R&D personnel* are calculated by dividing the total labour costs on intramural R&D by the total amount of 'R&D researcher equivalents'. One 'R&D researcher equivalent' is calculated by the sum of total business R&D researchers (in FTE) and *half* of the amount of R&D supporting personnel (in FTE). The reason for dividing the amount of R&D supporting personnel FTE by a factor two is that the wages of R&D supporting staff constitute – on average – half of the wages of R&D researchers. This

variable is calculated by Erken *et al.* (2004), based on data from the Standard Occupational Classification System of the US.

- The *entrepreneurship ratio* – also referred to as the business ownership rate – is calculated as the number of entrepreneurs as a percentage of the total labour force. The indicator *innovative entrepreneurship* measures the percentage of SMEs with in-house innovation, as defined by the Community Innovation Survey (CIS).
- *R&D stimulation by the government* encompasses R&D tax incentives (data from the beta index), R&D subsidies and R&D orders commissioned by the government. Data with regard to R&D tax incentives in Slovenia are missing (Slovenia is not included in the OECD beta index). Because tax incentives for R&D are only given a low priority in Slovenia (see Van Pottelsberghe *et al*., 2003), this does not pose serious problems in the benchmark analysis.
- *Taxation* and the *costs of R&D personnel* are 'negative' location factors for the attraction of R&D. A lower score on one of these factors implies a more attractive R&D investment climate. For both indicators, the scale on which the location factors are measured is reversed. For instance, we reverse the scale on total tax revenues (as a percentage of GDP) by calculating the tax-free proportion: 100% - tax rate.

CHAPTER 9

Total factor productivity and the role of entrepreneurship

9.1 INTRODUCTION

The explanation of economic growth is the essence of the field of economics. Neoclassical economists (Solow, 1956; Swan, 1956) focused on labour growth and capital accumulation as drivers of economic growth and treated technological progress as exogenous. Lucas (1988), Romer (1990) and Jones (1995) extended the neoclassical growth model by endogenising technological change. This was done by interpreting the creation of knowledge as an endogenous process, dependent on the amount of human capital (Lucas, 1988) or, more specifically, human capital allocated to R&D activities (Romer, 1990; Jones, 1995).

Indeed, there is a strong empirical relationship between productivity and R&D (Lichtenberg, 1993; Coe and Helpman, 1995, 2008; Bassanini *et al.*, 2001; Guellec and Van Pottelsberghe de la Potterie, 2004; Khan and Luintel, 2006). The usual and obvious critique, however, is that it is not R&D but innovation that actually spurs productivity growth. An important link between R&D and innovation is thought to be organisation, and entrepreneurship in particular (Audretsch and Keilbach, 2004a, 2004b, 2004c; Michelacci, 2003). Although the impact of entrepreneurship on economic growth and employment has been subject to extensive empirical research (Audretsch and Thurik, 2001a; Carree and Thurik, 2003; Van Stel *et al.*, 2005; Thurik *et al.*, 2008; Thurik, 1999), entrepreneurship is absent in studies that examine the long-run relationship between economic variables and economic growth or productivity development (Bleaney and Nishiyama, 2002; Van Praag and Versloot, 2007). The absence of a clear long-run relationship between entrepreneurship and economic growth and/or productivity makes the alleged importance of entrepreneurship in the academic debate somewhat vulnerable. In fact, the OECD recognises that, despite the undisputed attention given to entrepreneurship in policy, the importance of entrepreneurship for growth is still ambiguous: ‘*Researchers argue about the link between entrepreneurship and growth, but everybody wants entrepreneurship, even if the link to growth is not clear’* (OECD, 2006, p. 3).

We can only speculate about the reasons why entrepreneurship is omitted from longitudinal empirical research dealing with the drivers of growth. One cause could be the lack of high-quality systematic entrepreneurship data. Another could be the strong relationship between entrepreneurship measures and the level of economic development (Thurik *et al.*, 2008). In this chapter, we will use a new data set of business ownership data from the Compendia database (Van Stel, 2005), and use the deviation of the actual level of business ownership from an *'equilibrium' business ownership rate* (Carree *et al.*, 2007) as our entrepreneurship variable. Our approach is to re-estimate the models introduced in five seminal studies on the drivers of productivity development (Coe and Helpman, 1995; Engelbrecht, 1997; Griffith *et al.*, 2004; Guellec and Van Pottelsberghe de la Potterie, 2004; Belorgey *et al.*, 2006) using one single data set incorporating entrepreneurship to extend these models. Ultimately, all drivers of the five approaches plus controls are specified in an 'all in the family'-estimation. We will show that, regardless of the specification to explain productivity, entrepreneurship has a significant positive impact on productivity development. Our data set covers a thirty-two year period (1971-2002) of twenty OECD countries.

The structure of the chapter is as follows. Section 9.2 presents a theoretical framework for productivity analysis. Section 9.3 continues with a discussion of the determinants of productivity from an empirical perspective. Section 9.4 describes the model, data and variables used in this study. Section 9.5 presents the empirical results of our analyses and Section 9.6 concludes.

9.2 THE FRAMEWORK FOR PRODUCTIVITY ANALYSIS

The production function approach provides a starting point for productivity analysis (Section 9.2.1). Based on this approach, the relationship between growth, total factor productivity and other drivers of growth can be made explicit. From the production function approach we turn to the more recently developed endogenous growth models (Section 9.2.2). These endogenous growth models relate to the production function analysis and provide theoretical ground for empirical analysis regarding the drivers of total factor productivity (Section 9.3).

9.2.1 Production function approach: components of labour productivity growth

Solow (1956) and Swan (1956) were the first to model how the economy responds to changes in the investment rate, the growth of labour supply and technological progress. This resulted in the neoclassical growth model, also called the 'Solow model' or 'Solow-Swan model', which is still the leading framework for explaining economic growth and productivity growth. Related to the neoclassical growth model is the method of growth accounting. Growth accounting has its roots in work by Abramovitz (1956) and Solow (1957) and, in an earlier stage, Tinbergen (1942). It refers to decomposing economic growth and labour productivity growth into different components. After accounting for capital and labour, an unexplained technological component of economic growth remains. In growth accounting analyses, this became known as the ‘Solow residual’, also referred to as total factor productivity (TFP) or multi-factor productivity (MFP).[160]

Mankiw *et al.* (1992) added human capital to the neoclassical growth model, which resulted in the ‘augmented Solow model’. Based on the augmented Solow model, the following Cobb-Douglas production function can be taken as a starting point for productivity analysis (Van Bergeijk *et al.*, 1997):

$$Y = TFP \cdot K^{\alpha} \cdot L_{eff}^{\beta} \tag{9.1}$$

In equation (9.1), Y represents gross domestic product of firms. K and L_{eff} represent (physical) capital input and the use of effective labour by firms, respectively. Effective labour is equal to the amount of ‘raw’ labour and the amount of human capital allocated to production. Raw labour encompasses the skills that employees naturally possess and human capital embodies skills that are acquired through education and training (Romer, 2001). Expressed in growth rates, equation (9.1) approximates to:[161]

$$\dot{Y} = \dot{TFP} + \alpha \dot{K} + \beta \dot{L}_{eff} \tag{9.2}$$

Assuming constant returns to scale ($\alpha + \beta = 1.0$), we can derive the following relationship for labour productivity growth from equation (9.2):

$$(\dot{Y/L}) = \dot{TFP} + \alpha\,(\dot{K/L}) + \beta\,(\dot{L_{eff}/L}) \tag{9.3}$$

In equation (9.3), L represents input of labour measured as total hours worked. Equation (9.3) shows that labour productivity growth depends on TFP growth, the growth of the capital-labour ratio (also referred to as capital deepening) and the growth of effective labour per unit of labour. Since effective labour is the sum of raw labour (to be denoted by RL) and human capital (to be denoted by HC), the following definition relationship holds for the growth of effective labour per unit of labour:

[160] Total factor productivity growth is the residual of the growth of gross domestic product (GDP), after the contributions of labour and capital are subtracted. In this sense, TFP can be regarded as an indicator of the technological capacity of countries, because it measures how efficiently the production factors capital and labour are combined in generating value added.

[161] It is more accurate to formulate equation (9.2) as: $\Delta\ln(Y) = \Delta\ln(TFP) + \alpha\,\Delta\ln(K) + \beta\,\Delta\ln(L_{eff})$. However, for the remaining part of our exposition it is more useful to formulate equation (9.2) in terms of growth rates.

$$(\dot{L}_{eff} / L) = \left(\frac{RL_{t-1}}{L_{eff,t-1}} \right) (\dot{RL}/L) + \left(\frac{HC_{t-1}}{L_{eff,t-1}} \right) (\dot{HC}/L) \tag{9.4}$$

Supposing that raw labour per unit of labour (*RL*/*L*) is constant, (9.4) can be read as:

$$(\dot{L}_{eff} / L) = \left(\frac{HC_{t-1}}{L_{eff,t-1}} \right) (\dot{HC}/L) \tag{9.5}$$

Combining (9.3) and (9.5) leads to the following basic equation for the explanation of labour productivity growth:

$$(\dot{Y}/L) = \dot{TFP} + \alpha\,(\dot{K}/L) + \beta \left(\frac{HC_{t-1}}{L_{eff,t-1}} \right) (\dot{HC}/L) \tag{9.6}$$

Using γ for the elasticity with respect to human capital, equation (9.6) becomes:

$$(\dot{Y}/L) = \dot{TFP} + \alpha\,(\dot{K}/L) + \gamma(\dot{HC}/L) \tag{9.7}$$

It is possible to proxy the elasticities for *TFP*, physical capital per hour worked (*K*/*L*) and human capital per hour worked (*HC*/*L*) by using input shares of the production factors within total value added. The share of physical capital within the Cobb-Douglas production function is usually fixed at 1/3, which is approximately the share of capital income in total value added (Romer, 2001, p. 23). For effective labour a share of 2/3 remains. Based on wage earnings distributions for different kinds of labour (high-skilled versus low-skilled labour), the share of human capital in total effective labour can be fixed at approximately 2/3 (Mankiw *et al.*, 1992; Van Bergeijk *et al.*, 1997; Gundlach, 1997, 2001). Given that the share of effective labour within total value added can be fixed at 2/3 as well, the elasticity of human capital can be broadly determined at 4/9 (= 2/3 × 2/3). Using these elasticities, equations (9.6) and (9.7) become:

$$(\dot{Y}/L) = \dot{TFP} + 1/3\,(\dot{K}/L) + 4/9\,(\dot{HC}/L) \tag{9.8}$$

We can also write equation (9.7) in levels:

$$(Y/L) = TFP \times (K/L)^{\alpha} \times (HC/L)^{\gamma} \tag{9.9}$$

Equation (9.9) is equivalent to the following log-linear equation, where 'ln' denotes the natural logarithm:

$$\ln(Y/L) = \ln(TFP) + \alpha \ln(K/L) + \gamma \ln(HC/L) \qquad (9.10)$$

Based on the augmented Solow model, we can derive the long-run equilibrium relationship for the growth and the level of labour productivity. We have to take into account that the physical capital stock is the result of investments over a long period of time and that investments are dependent on gross domestic product through the investment rate. This implies that in the long run the capital-labour ratio (*K*/*L*) is strongly dependent on labour productivity (*Y*/*L*). As a consequence, TFP and human capital not only have a direct impact on labour productivity, but also an indirect effect through the capital-labour ratio. We will not derive the long-term equilibrium relationship because of its highly technical explanation (Jones, 2002a), but the essence can be explained easily. If we assume that human capital is exogenously determined, we can draw from equations (9.9) and (9.10) that TFP affects labour productivity by an elasticity of $1/(1-\alpha)$ in the long run.[162] Assuming a value of 1/3 for α (as indicated above), this elasticity would be 1.5. The multiplier of $1/(1-\alpha)$ for the long-term effect also applies to the direct effect of human capital and the direct effects of exogenous determinants of the capital-labour ratio, i.e. the investment rate and quality improvements of capital. However, in that case the elasticities for the direct effects on labour productivity (being α for the investment rate and quality improvements of capital and γ for human capital per unit of labour) must be taken into account as well.

The productivity equations in the 'augmented' Solow model provide a solid foundation for empirical analysis on the determinants of productivity growth. Within the 'augmented' Solow model, TFP growth emerges as a residue after adjusting total value added for the impact of the capital-labour ratio and the amount of human capital per unit of labour. However, there is an important impediment when constructing this TFP measure: the impact of the capital-labour ratio and the impact of human capital per unit of labour must be quantified. Quantifying the capital-labour ratio is fairly simple, because data on capital are directly available in internationally comparable statistics. Furthermore, the elasticity of the capital-labour ratio is conventionally fixed at approximately one-third. The impact of human capital, on the contrary, is more difficult to quantify: various factors can affect the amount of human capital, such as the average duration of education (being an indicator of the average level of education), the

[162] The principle behind the long-run multiplier of 1.5 from TFP to labour productivity can be found in the *endogenous capital deepening* effect. By definition, a higher TFP leads directly to a higher labour productivity. However, there is an additional effect on labour productivity through the accumulation of capital (i.e. the endogenous capital deepening effect). Assuming a fixed investment quote (investments as a ratio of GDP), higher labour productivity leads to more investment per unit of labour. This results in more accumulation of capital per unit of labour, which will lead to a higher capital/labour ratio. In the long run, the percentage effect on the capital/labour ratio will be equal to the percentage effect on investment per unit of labour. The higher capital/labour ratio provides an additional impulse to labour productivity (the effect is dependent on coefficient α in equation (9.10)).

employment rate and the amount of hours worked. In this chapter, we will not fix the impact of these human capital variables *a priori*, but estimate their effects empirically. This is possible by using a broader definition of total factor productivity than is used in the 'augmented' Solow model. In our definition of total factor productivity, the effect of human capital per unit of labour is included as well. Many other empirical studies use this definition of TFP (Coe and Helpman, 1995; Engelbrecht, 1997 and Guellec and Van Pottelsberghe, 2004). Using the broad definition of TFP, the following equations become our starting point:

$$(\dot{Y}/L) = \dot{TFP} + \alpha\,(\dot{K}/L) \tag{9.7b}$$

$$\ln(Y/L) = \ln(TFP) + \alpha\,\ln(K/L) \tag{9.10b}$$

9.2.2 Endogenous growth models

The neoclassical growth theory characteristically treats technological progress as an exogenous variable. Endogenous growth models have been developed in which technological progress is explained by human capital and/or R&D (Romer, 1990; Jones, 1995; Young, 1998). The R&D-based endogenous growth models start from the so-called knowledge production function:

$$\Delta A = \xi\, L_A{}^{\lambda} \cdot A^{\phi} \tag{9.11}$$

In equation (9.11), ΔA represents the development of new knowledge, A represents the existing stock of knowledge and L_A is an indicator of the amount of human capital used in R&D processes. As a measure of the (technological) knowledge stock, variable A is related to total factor productivity in traditional production functions explaining gross domestic output. Important for the implications of the knowledge production function on total factor productivity growth are the coefficients λ and ϕ (Jones, 1995). The value of ϕ is determined by two opposite effects: the positive 'standing on shoulders' effect – it is easier to generate new knowledge when there is a larger body of existing knowledge – and the negative 'fishing out' effect – the development of new knowledge is more difficult if more knowledge already exists. In addition, there is the risk of duplication of R&D activities. If duplication occurs, λ is smaller than 1. Finally, ξ represents the general productivity coefficient for the development of knowledge, given the existing knowledge stock A.

Jones (1995) shows that coefficient ϕ should be smaller than 1. In the Jones model this implies that a once-and-for-all increase in the *level* of R&D personnel in relation to the work force does not result in a permanent effect on the *growth* of the knowledge stock, but results in a higher steady-state level of the knowledge stock in the long run. If the coefficient ϕ would be 1 or higher than 1, as is the case in the Romer model, a once-and-for-all rise in the level of R&D would lead to a permanently higher productivity growth. Because domestic knowledge creation also depends on the knowledge stock abroad, equation (9.11) can easily be extended, following Porter and Stern (2000):

$$\Delta A = \xi \, L_A{}^{\lambda} \cdot A^{\phi} \cdot A_{for}{}^{\psi} \tag{9.12}$$

As A_{for} denotes the knowledge stock abroad, equation (9.12) shows that the development of domestic knowledge is dependent on the R&D efforts by a country itself, its own knowledge stock and the knowledge developed elsewhere. The two latter effects represent domestic and foreign knowledge spillovers, respectively. In our empirical analysis, we will also discriminate between these two effects (Coe and Helpman, 1995; Guellec and Van Pottelsberghe de la Potterie, 2004). Although the endogenous growth models have been tested by calibrating the developed models (Jones, 2002b), it is difficult to empirically estimate endogenous growth models, developed from a theoretical perspective. The quantification of the knowledge stock in endogenous growth models is accompanied with statistical difficulties, because this variable is not directly observable. Furthermore, the non-linear structure of the knowledge production function complicates an empirical estimation. As a consequence, the R&D capital approach is used more often in empirical research (Griliches, 1998, 2000). Both the knowledge accumulation function from endogenous growth theory and the R&D capital approach are based on accumulated knowledge as a result of R&D efforts. However, the benefit of the R&D capital approach is the straightforward calculation of the stock of R&D capital (see next section).[163] The R&D capital approach links theoretical insights on the drivers of growth originating from endogenous growth theory to opportunities to empirically test the importance of these drivers.

A further advantage of the R&D capital approach is that depreciation of knowledge (because of obsolescence) is explicitly taken into account. In endogenous growth models this occurs implicitly via the efficiency parameter ξ of the knowledge production function. This parameter includes an effect of creative destruction: newly produced knowledge partly replaces already existing knowledge (Jones and Williams, 2000). This approach is applicable at the global level. At the national level (as well as the industrial and micro level), however, depreciation is largely exogenous, dependent on the worldwide development of new knowledge. The R&D capital approach takes this into account by assuming an exogenous depreciation rate on the one year lagged R&D capital stock of a country (or sector or firm within a country).

9.3 DETERMINANTS OF TOTAL FACTOR PRODUCTIVITY

The present section deals with the drivers of total factor productivity growth, which will play an important role in our empirical exercises, such as R&D capital, a mechanism for technological

[163] Furthermore, the R&D capital approach can be used for research on the micro and industry level as well. This is not possible using the knowledge production function of the endogenous growth theory.

catching-up, entrepreneurship, labour participation, human capital, openness to foreign trade and profitability.

9.3.1 R&D capital approach

Much empirical work explaining productivity growth is inspired by endogenous growth theory, but uses the R&D capital approach for estimating the effect of R&D. The R&D capital stock is calculated using an accumulation function, in which the R&D capital stock (in volumes) in period *t* is equal to new R&D investments (in volumes) in period *t* plus the stock at period *t*-1 minus depreciation:

$$RDK = RD_t + (1-\delta)RDK_{t-1} \tag{9.13}$$

In equation (9.13) *RD* represents the volume of R&D expenditure, *RDK* represents the volume of R&D capital and δ the depreciation rate of R&D capital.

A large body of literature empirically deals with the relationship between total factor productivity and R&D using the R&D capital approach (Coe and Helpman, 1995; Guellec and Van Pottelsberghe de la Potterie, 2004; Jacobs *et al.*, 2002; Griliches and Lichtenberg, 1984; Griliches, 1998). These studies generally find strong results concerning the contribution of R&D capital to TFP growth. In the present study, we will follow the approach of Coe and Helpman (1995) and Guellec and Van Pottelsberghe de la Potterie (2004), who discriminate between the impact of domestic and foreign R&D on productivity growth.

An advantage of the approach of Coe and Helpman (1995) is that the impact of domestic R&D capital is dependent on the economic size of countries. Larger economies benefit more than smaller ones from domestic R&D capital. First, the R&D of larger OECD countries constitutes a larger share within worldwide R&D than the amount of R&D conducted by smaller countries. Secondly, in larger countries the spillovers of domestic R&D flow to foreign countries to a lesser extent and will be absorbed principally within the home country. Finally, large countries perform R&D across a wide array of possible R&D activities; thereby better exploiting complementarities (Coe and Helpman, 1995). In the study by Coe and Helpman, the impact of foreign R&D on domestic productivity depends on the import shares of countries.[164] The idea is that openness to foreign trade functions as a mechanism to benefit from knowledge developed abroad (Romer, 1991, 1992; Grossman and Helpman, 1991; Barro and Sala-i-Martin, 1995). The empirical results indeed show that foreign R&D capital has a stronger effect on domestic productivity the more open a country is to foreign trade.[165] Based on these two mechanisms

[164] The results in Guellec and Van Pottelsberghe de la Potterie (2004) show that foreign R&D capital has a larger impact on domestic productivity if a country has a larger domestic R&D stock. The idea behind this mechanism is that countries need to conduct research themselves to build up ‘absorptive capacity’ in order to benefit from research performed abroad (Cohen and Levinthal, 1989).

[165] There is a debate in the literature about the transmission channel of international R&D spillovers, being either trade (Coe and Helpman, 1995; Grossman and Helpman, 1991) or foreign direct investments (Branstetter, 2006).

(scale effect and impact of openness), Coe and Helpman (1995, p. 875) conclude: *"…our estimates of TFP with respect to R&D capital stocks suggest that in the large countries the elasticity is larger with respect to the domestic R&D capital stock than with respect to the foreign capital stock, while in most of the smaller countries the elasticity is larger with respect to the foreign capital stock."*

The role of public R&D capital as a major determinant of productivity is less unambiguous. Next to a strong impact of domestic private R&D capital and foreign R&D capital, Guellec and Van Pottelsberghe de la Potterie (2004) find a significant and strong positive impact of public R&D capital on the development of total factor productivity. In contrast, Khan and Luintel (2006) find a significant negative impact of the public R&D capital stock on total factor productivity and Bassanini *et al*. (2001) find a significant negative impact of public R&D intensity on GDP per capita.

9.3.2 Catching-up

An alternative way to model the impact of knowledge produced abroad is derived from the 'technology gap' theory, which states that countries with a low level of technological development are able to benefit more from knowledge abroad than do countries that are technologically leading or close to the technological frontier (Fagerberg, 1987; Cameron *et al.*, 1998). The set up of Griffith *et al.* (2004) relates to both the R&D spillover literature and the convergence literature, because the authors model a direct effect of domestic R&D and a separate catching-up mechanism.[166] This catching-up mechanism captures technology transfer as follows: the further a country lags behind the technological frontier, the greater the potential to increase TFP growth through technology transfer from more advanced countries. Next to a direct catching-up effect, Griffith *et al.* find evidence for interaction effects of domestic R&D and human capital with respect to catching-up, implying that domestic R&D and human capital in a country both have a positive impact on the catching-up potential of countries. This supports the Cohen and Levinthal (1989) idea of 'absorptive capacity', meaning that countries need a domestic research base in order to absorb technology developed abroad.

A conventional way to model catching-up is by using the technological distance between countries based on the level of labour productivity per person employed (Dowrick and Rogers, 2002; Frantzen, 2000) or standard of living, which is usually measured by GDP per capita (Engelbrecht, 1997; Fagerberg and Verspagen, 2002). Griffith *et al.* (2002) use differences in TFP levels between countries to model their catching-up variable. In the present study, we

Some studies argue that international spillovers are not driven by trade flows (Keller, 1998; Kao *et al*., 1999), while others find a robust positive effect of international R&D spillovers transferred through intermediate goods imports (Lee, 2005). Van Pottelsberghe and Lichtenberg (2001) find strong evidence that foreign R&D can affect home productivity through trade (i.e. imports) and FDI (i.e. outward foreign direct investments). For simplicity, we assume that international R&D spillovers are driven through trade as the dominant transition mechanism.

166 Coe and Helpman (1995) and Guellec and Van Pottelsberghe de la Potterie (2004) do not include a catching-up variable in their empirical models.

choose an alternative approach by using a direct measure of the technological distance between countries. Labour productivity and total factor productivity are not only influenced by the level of technological development, but depend on a other factors as well. In order to gain an accurate measure of technological distances between countries, one should adjust productivity levels for other important factors. In practice, however, these adjustments are difficult to conduct. Therefore, in Section 9.4 we will introduce an alternative catching-up variable based on patents granted by the USPTO.

9.3.3 Entrepreneurship

Investments in knowledge and research alone will not advance productivity automatically, because not all developed knowledge is economically relevant (Arrow, 1962). Schumpeter (1947) points out that entrepreneurship is an important mechanism for the creation of value added within an economy: *"the inventor creates ideas, the entrepreneur 'gets things done'"*. Braunerhjelm (2008) argues that while neoclassical growth theory threats knowledge production as exogenous, knowledge diffusion (i.e. the critical mechanism for creating growth) is exogenous in the endogenous theory. Although several attempts have been made to introduce entrepreneurship in endogenous growth models (Segerstrom *et al*., 1990; Aghion and Howitt, 1998), the essence of the Schumpeterian entrepreneur is missed in these models (Braunerhjelm, 2008, p. 475).[167] Inspired by this limitation of the endogenous growth theory, Audretsch *et al.* (2006) and Acs *et al.* (2004, 2005) develop a model that introduces a filter between knowledge in general and economic-relevant knowledge and indentify entrepreneurship as a mechanism that reduces this so-called 'knowledge filter'. Only parts of the total knowledge stock can be transformed in economic-relevant knowledge and transforming 'raw' knowledge into firm-specific knowledge takes efforts and costs. In this sense, the knowledge filter can be interpreted as a barrier impeding investments in new knowledge from spilling over for commercialisation (Audretsch, 2007). The knowledge filter must be penetrated in order to adjust knowledge, before it can contribute to economic growth. Actors willing to penetrate the knowledge filter are incumbent and new firms. Incumbent firms have the capabilities to penetrate the filter (Cohen and Levinthal, 1990) and new firms are eager and motivated to do the same in order to force market entry or capture market share (Kirzner, 1997). This implies that entrepreneurship is an important transfer mechanism to facilitate the process of knowledge spillovers (Audretsch *et al.*, 2006; Mueller, 2006). As both incumbent firms and new firms are willing to penetrate the knowledge filter, a 'stock' indicator for entrepreneurship, such as the business ownership rate, is more appropriate for our analysis compared to an entrepreneurship variable that merely captures the dynamics of the entrepreneurial process, such as the start-up ratio.

[167] The neo-Schumpeterian models primarily design entry as an R&D race between existing firms where only a small part of total R&D efforts will result into actual innovations. Braunerhjelm (2008) argues that innovation processes encompass much more than solely R&D races between large incumbents, which solely encompass quality improvements of existing goods.

Acs *et al.* (2004, 2005) and Plummer and Acs (2004) test the endogenous growth model with entrepreneurship incorporated. These studies show a positive impact of entrepreneurship on growth. The strongest growth effect relates to the importance of entrepreneurship in exploiting spillovers originating in a country's knowledge stock (R&D). These outcomes provide ground for the view that entrepreneurship serves as a conduit for spillovers of knowledge. It is important to keep in mind that R&D by itself is neither a growth guarantee nor will resulting growth happen instantaneously. Similarly, entrepreneurship is insufficient for propelling growth: it has to exploit knowledge (R&D) in order for positive growth effects to emerge (Acs *et al.*, 2005). This conclusion is also drawn by Michelacci (2003), who considers an endogenous growth model where innovation requires the matching of an entrepreneur with a successful invention. Next to discussing theoretical properties of his model, Michelacci also provides estimations for the US over the period 1950-1990. In this exercise, innovation is measured by an index of patent applications, research efforts are indicated by the number of scientists and engineers involved in R&D as a ratio of population and entrepreneurship is measured as the population of self-employed. The empirical tests show that the relationship between the number of innovations and research efforts is concave and hump-shaped. Based on this result, Michelacci concludes that an economy allocating too many individuals towards the research sector will produce too many inventions that will be wasted, because there are insufficient entrepreneurs to implement them.

The impact of entrepreneurship on economic growth and employment has been subject to empirical research (Audretsch and Thurik, 2001a; Carree and Thurik, 2003; Van Stel *et al.*, 2005; Thurik *et al.*, 2008). Audretsch and Keilbach (2004a) use the number of start-ups between 1989-1992 divided by thousands of the population as an indicator for entrepreneurship explaining German regional growth of labour productivity per employee (covering 327 West German regions in 1992).[168] The elasticity for the effect of entrepreneurship on labour productivity is estimated on 0.17. This means that a 1% increase in the start-up rate of a region results in a rise of labour productivity by 0.17%.[169] The dynamics of labour productivity is examined in Audretsch and Keilbach (2004c) by looking at the impact of start-up rates between 1989-1992 on the growth of labour productivity between two years: 1992 and 2000. They find a significant positive effect of entrepreneurship. All three studies by Audretsch and Keilbach (2004a, 2004b and 2004c) however, remain limited to data covering German regions and few years of observation. Audretsch and Keilbach (2004c, p. 615) state that: *"whether these results hold for other countries or for other time periods can only be ascertained though subsequent research"*. Holtz-Eakin and Kao (2003) find a significant positive relationship between birth

[168] Besides start-ups rates, Audretsch and Keilbach (2004a, 2004b) use start-ups activity in high-tech manufacturing (with a R&D intensity above 2.5%) and the number of start-ups in ICT industries as alternative entrepreneurship indicators. Knowledge capital is included in the model as the number of employees engaged in R&D activities.

[169] Audretsch and Keilbach (2004b) find similar effects of entrepreneurship on regional economic output (elasticity of 0.12). The methodology used in Audretsch and Keilbach (2004b) is equivalent to that in Audretsch and Keilbach (2004a). Audretsch and Keilbach (2004c) find a significant positive effect of entrepreneurship on the *growth* of regional labour productivity between two years of observation: 1992 and 2000.

and death rates and productivity levels in cross-section panel estimations for US states. In contrast, estimations using the ‘within’ variation of productivity across US states sketch a different picture: the effects of the lagged values of the birth and death rate on productivity are insignificant and show negative signs.[170] Due to interrelated dynamic effects, however, the ultimate negative effect of a shock in the birth or the death rate on productivity remains very limited. Bleaney and Nishiyama (2002) empirically test various growth models, but none of these models contain entrepreneurship as a determinant. Van Praag and Versloot (2007) present an overview of the recent empirical literature which claims that entrepreneurship has an important economic value. The relationship between entrepreneurship and levels of productivity has only been examined on the firm level and they do not find empirical studies that confirm a long-run relationship between entrepreneurship and growth or productivity.[171] Carree and Thurik (2008) discriminate between the short- and long-run effect of new business creation on productivity, but they only find a significant positive effect of entrepreneurship in the short term. In short: entrepreneurship is either absent in studies that examine the long-run relationship between economic variables and economic growth c.q. productivity development or its effect is insignificant or negative in the long run.

The use of entrepreneurship measures to explain productivity is burdened by the role that economic development plays when explaining levels of entrepreneurship. The negative relationship between business ownership and economic development is well documented (Kuznets, 1971; Schultz, 1990; Yamada, 1996; Iyigyun and Owen, 1998). The growing importance of economies of scale is mentioned as the explanation (Chandler, 1990; Teece, 1993). The reversal of this trend is first observed by Blau (1987) and Acs *et al*. (1994) and attributed to technological changes leading to a reduction of the role of economies of scale (Piore and Sabel, 1984; Jensen, 1993; Audretsch and Thurik, 2001b and 2004).[172]

Given the strong relationship between entrepreneurship and the level of economic development, it becomes essential to correct the level of entrepreneurship for the level of economic development. Otherwise entrepreneurship becomes a proxy for economic development. In the present study, we use the business ownership rate as a proxy for entrepreneurship.[173] We correct the business ownership rate for level of economic development using the setup of Carree *et al*. (2002, 2007). They introduce the *‘equilibrium’ business ownership rate* – which is a function of

[170] These ‘within’ estimates – preferred by the authors – imply that each variable is transformed to deviations from the state-specific mean. This way, state-specific effects are filtered out, which obviates possible unobserved heterogeneity.

[171] Beck *et al*. (2005) find no robust cross-sectional relation between size of the SME sector in the manufacturing labour force and economic growth using a sample of 45 countries. These variables could be interpreted as proxies for entrepreneurship and TFP, respectively.

[172] See also Thurik *et al*. (2008) and Carree and Thurik (2003) for a survey of the many mechanisms of the relationship between the business ownership rate and economic development.

[173] The business ownership rate is defined as the number of business owners (including all sectors except the agricultural sector) in relation to the labour force. Business owners include unincorporated and incorporated self-employed individuals, but exclude unpaid family workers. See Van Stel (2005) for more information on how this variable has been calculated. Data for 1970 and 1971 have been extrapolated.

GDP per capita – in a model where deviations from this rate determine both the growth of business ownership and the pace of economic development.[174] They investigate both an L-shaped 'equilibrium' business ownership rate (where the role of economies of scale is fading out) and a U-shaped one (with a manifest reversal of the trend as mentioned above). They conclude that the L-shape is to be preferred on the basis of empirical fit (also see Annex 4). As the entrepreneurship variable in the present chapter we will use the development of the deviation of countries from their L-shaped 'equilibrium' business ownership rate. In other words: levels in excess of the 'equilibrium' business ownership rate are hypothesized to lead to higher TFP levels and levels below it to lower TFP levels. Further details on the construction of this variable are presented in Section 9.4.

9.3.4 Labour participation and human capital

Quality improvements of labour due to education and training are often referred to as human capital (Romer, 2001, p. 133). The empirical support for a direct effect of human capital on labour productivity used to be limited (Behabib and Spiegel, 1994; Casseli *et al*., 1996). According to De la Fuente and Doménech (2006, 2000) this is due to lack of high-quality data. Using high-quality human capital data (the average education level of the working-age population represented by the average years of education) in a panel analysis for 21 OECD countries over the period 1960-1990, De La Fuente and Domenéch (2006, 2000) find strong empirical support for the importance of human capital for productivity. In their preferred equation, they find an elasticity of 0.27 for the effect of the average years of education on labour productivity. Bassanini and Scarpetta (2002, 2001) extended the dataset of De La Fuente and Domenéch (2006, 2000) and find a strong effect of the average years of education on GDP per capita in a panel analysis for 21 OECD countries covering the period 1971-1998. According to their results, an increase in the average duration of education of the population aged 25-64 by one year raises GDP per capita by approximately 6% in the long run.[175]

Next to the quality of the production factor labour, the amount of labour used in the production process is important. High labour participation is often characterized by more deployment of less-productive labour, which lowers labour productivity due to a negative effect on the amount of human capital per unit of labour (Pomp, 1998). Belorgey *et al.* (2006) find a negative impact of the employment rate (persons employed as a ratio of total population) on productivity. The

[174] The model investigates the shape of the *'equilibrium' business ownership rate*, the error correction mechanism (the speed of convergence towards this rate) and the out-of-equilibrium growth penalty (Audretsch *et al*., 2002).

[175] This effect includes the indirect impact of human capital on productivity through a higher capital-labour ratio (Section 9.2 and footnote 162). We adjust for the indirect effect on the capital-labour ratio in order to obtain the *direct* effect of human capital on total factor productivity. Assuming a weight of capital of 1/3 (Section 9.2), the TFP effect ends up to be one third lower than the elasticity of 6% representing the effect of human capital on GDP per capita. This implies that an increase in the average duration of education by one year would have a direct effect on TFP of 4%. One additional year of education within the OECD area is approximately equal to a rise of the average duration of education of 10%. As a consequence, a rise of the average duration of education of 1% results in a rise of total factor productivity of 0.4%. This elasticity equals the derived weight of human capital of 4/9 (= 0.44) in equation (9.8) of Section 9.2.

long-run elasticity found is approximately -0.5.[176] Recent empirical research by Bourlès and Cette (2005, 2007) and Donselaar and Segers (2006) find similar long-run elasticities. For instance, Bourlès and Cette (2007) conclude that a one point variation of the employment rate (persons engaged as a share of population) changes hourly labour productivity in the long run by -0.43 percent.

Besides participation levels, the number of hours worked per person employed in an economy has implications for the level of labour productivity. If less productive employees work in part-time jobs more often, the productivity level will be higher in countries with more people working part-time jobs. Furthermore, working fewer hours may exert a positive impact on productivity if less fatigue occurs among workers or if employees work harder in the shorter number of active hours. Belorgey *et al.* (2006), Bourlès and Cette (2005, 2007) and Donselaar and Segers (2006) provide empirical ground for the existence of a negative relationship between hours worked and productivity. The effects are again remarkably similar. Belorgey *et al.* (2006) finds a negative long-run elasticity of -0.37 between the amount of hours worked and productivity (Annex 2). In accordance with this result, Bourlès and Cette (2007) conclude that a one percent variation in hours worked per person employed changes long-run productivity per hour worked by -0.42 percent.

9.3.5 Other variables

Above we dealt with knowledge (through R&D and catching-up), entrepreneurship and human capital as the main drivers of total factor productivity. Below some other variables will be discussed. First, the *sector composition* of countries could have implications for the productivity development of countries. Erken and Ruiter (2005, see Chapter 5 of this thesis) show that the sector composition has a significant impact on the R&D intensity, which ultimately affects productivity indirectly through the R&D capital stock. Next to this mechanism, we expect that the sector composition of an economy affects the opportunities to transform R&D-based knowledge into actual innovations. In our empirical analysis, we take this latter effect into account by modelling the sector composition variable as the share of high-tech and medium-high-tech industries within total economy in relation to the R&D capital intensity of countries.

The role of *openness to foreign trade* as a transfer mechanism was previously addressed in this chapter when discussing the impact of R&D on total factor productivity. However, we expect that openness has a separate impact on total factor productivity as well. A more open economy implies a higher level of competition from abroad which functions as an incentive for firms to innovate, given a certain amount of R&D capital. Furthermore, more competition stimulates firms to reduce their X-inefficiencies.[177] Using a dataset for 93 countries and using nine alternative indexes of trade policy, Edwards (1998) finds empirical evidence that more open

[176] See Annex 2 of this chapter for the derivation of the long-run elasticity of hours worked per person.

[177] X-inefficiencies are various forms of inefficiency caused by poor communication, ignorance or neglect by suppliers, buyers, managers or employees (Leibenstein, 1966).

countries experience a faster productivity growth. The openness variable used in our analysis is based on an indicator for foreign trade exposure developed by Bassanini *et al*. (2001). In the next section, we elaborate on the construction of the openness variable.

The *profitability* of businesses can have an important impact on total factor productivity. More firm profits support higher R&D expenditure by firms (Himmelberg and Petersen, 1994). In addition, higher profit expectations can motivate firms to innovate at a higher rate (given a fixed amount of R&D capital). Lastly, higher profits provide firms with financial means to stimulate innovation (given a fixed degree of R&D capital). Since there are no internationally comparable data available on firm profitability, the *capital income share* is used to capture the profitability effect. The capital income share is defined as gross capital income as a percentage of the gross value added of businesses. The negative counterpart of profitability is *taxation*. Taxation could have a negative impact on productivity: a higher rate of taxation implies negative incentives in certain markets, which consequently could result in a less efficient economy. For instance, a higher taxation rate reduces revenues acquired through innovation, which could reduce incentives to innovate. The taxation variable in our model is expressed as total tax revenues in relation to GDP.

Finally, we take into account the impact of the *business cycle* on the development of total factor productivity. Labour and capital endowments are not immediately adjusted to business cycle volatility, but follow with a certain time lag. As a consequence, total factor productivity fluctuates around an increasing trend over time. Two variables are included to account for the impact of the business cycle: the change in the unemployment rate and the deviation of gross value added of firms from a 5-yearly moving average (year *t*-2 through *t*+2) of gross value added of firms. In times of an economic boom, value added is higher than the trended development of value added and vice versa.

9.4 MODEL, DATA AND VARIABLES

The following standard fixed-effects linear model is used:

$$\ln(TFP_{i,t}) = \beta_0 + \beta_1(X_{i,t}) + \beta_i DUM_i + \beta_t DUM_t + \varepsilon_{i,t} \qquad (9.14)$$

In (9.14), *TFP* (for country *i* and year *t*) stands for total factor productivity per hour worked, 'ln' denotes the natural logarithm, *X* is a vector of dependent variables, DUM_i is a dummy variable for country *i*, DUM_t are time dummies for year *t* and ε is an idiosyncratic error term. Vector *X* is expressed in natural logs of the independent variables. In Table 9.1 these variables are made explicit, including data sources and some descriptive statistics. In Annex 5, a survey is presented of the typical specification of each model estimated in this chapter.

Table 9.1 Description of variables, data sources and descriptive statistics

Variable name	Description	Source	Mean	Median	Standard Deviation	Scale
TFP	Total factor productivity of firms, index (1995 = 1)	OECD Economic Outlook database, no. 78	0.893	0.909	0.139	Max: 1.432 Min: 0.384
BRD^{h}	Volume of domestic R&D capital of firms, index (1995 = 1)	OECD Main Science and Technology Indicators 2004/1	0.733	0.755	0.311	Max: 1.780 Min: 0.123
PRD^{h}	Volume of domestic R&D capital of public research institutions (universities and public research institutions), index (1995 = 1)	OECD Main Science and Technology Indicators 2004/1	0.801	0.811	0.226	Max: 1.396 Min: 0.213
RDS	Share of domestic R&D capital in total R&D capital in the ‘world’ (= 20 OECD countries in this study), %	OECD Main Science and Technology Indicators 2004/1	5.000	1.123	10.008	Max: 47.808 Min: 0.100
BRD^{f}	Volume of foreign R&D capital of firms (for 20 OECD countries), index (1995 = 1)	OECD Main Science and Technology Indicators 2004/1	0.791	0.774	0.211	Max: 1.261 Min: 0.398
PRD^{f}	Volume of foreign R&D capital (for 20 OECD countries) of public research institutions (universities and public research institutions), index (1995 = 1)	OECD Main Science and Technology Indicators 2004/1	0.842	0.818	0.142	Max: 1.136 Min: 0.586
$IMSH$	Import share, expressed as total imports in relation tot GDP	OECD Economic Outlook, no 75	0.307	0.288	0.145	Max: 0.844 Min: 0.054
HC	Average duration of education of the population aged 15-64	Bassanini and Scarpetta (2001, 2002)	4.185	3.586	2.667	Max: 11.277 Min: 0.155
BOR^*	Deviations from ‘equilibrium’ business ownership rate, index (1995 = 1). The business ownership rate is the amount of business owners as a percentage of the labour force	EIM Compendia Database, Carree *et al.* (2007)	0.864	0.893	0.174	Max: 1.267 Min: 0.369
CU	Catching-up variable in levels, based on accumulated patents granted by USPTO (using a depreciation rate) in relation to the labour force (US = 0, 1995 = 0)	USPTO data	14.431	7.379	23.319	Max: 144.508 Min: -29.495
CU^{RD}	Equal to *CU*, but multiplied with R&D capital intensity prior to accumulation in order to create patents stocks	USPTO data	0.964	0.744	1.240	Max: 4.802 Min: -1.308

Table 9.1 (continued)

Variable name	**Description**	**Source**	**Mean**	**Median**	**Standard Deviation**	**Scale**
LPAR	Labour participation measured by persons employed in relation to population, index (1995 = 1)	OECD Economic Outlook, no 75	0.999	0.100	0.075	Max: 1.275 Min: 0.085
HRS	Average hours worked per person employed, index (1995 = 1)	Total Economy Database (GGDC)	1.042	1.020	0.068	Max: 1.260 Min: 0.912
ΔUR	First difference in the unemployment rate	OECD Economic Outlook, no 75	6.004	5.543	3.733	Max: 18.437 Min: 0.003
SECCOM	Share of high-tech and medium-high-tech industry in gross domestic product, index (1995 = 1)	OECD STAN database	1.047	1.021	0.199	Max: 1.778 Min: 0.249
RDI	Domestic R&D capital intensity, measured as the volume of domestic R&D capital (private and public) in relation to GDP, in percentages	OECD Main Science and Technology Indicators 2004/1	0.917	0.967	0.177	Max: 1.561 Min: 0.340
BUSCYCLE	Variable covering the effect of the business cycle, measured as the deviation of gross value added of firms from a 5-yearly increasing moving average of gross value added of firms, index (1995 = 1)	OECD Economic Outlook, no 75	1.000	1.000	0.018	Max: 1.078 Min: 0.935
CIS	Capital income share, expressed as gross capital income in relation to gross value added, index (1995 = 1)	OECD Economic Outlook, no 75	0.919	0.934	0.176	Max: 1.672 Min: 0.340
TR	Total burden of taxation, expressed as total tax revenues in relation GDP, index (1995 = 1)	OECD Revenue Statistics	0.945	0.974	0.110	Max: 1.135 Min: 0.491
OPENECO	Variable representing the openness of the economy, defined as the volume of imports and exports in relation to GDP, adjusted for the scale of economies, index (1995 = 1)	OECD Economic Outlook, no 75	0.852	0.832	0.189	Max: 1.336 Min: 0.394
DUM^{91}_{GER}	Dummy for German reunion in 1991	-	-	-	-	-
DUM_i	Dummy variable for country *i*, included for all countries except the Netherlands	-	-	-	-	-
DUM_t	Dummy variable for year *t*, included for all years except 1995	-	-	-	-	-

To estimate our fixed-effects model, we use data for a period of thirty-two years (1971-2002) and twenty countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US. The data originate from a number of sources which will be discussed below. Most variables are expressed in levels and indices (1995 = 1). Comparability over time is achieved using constant prices to create 1995 volumes. Data in different national currencies were made comparable between countries by using US dollar purchasing power parities (PPP in US$).

TFP levels, the labour participation variable and some control variable are based on data from the OECD Economic Outlook database. The number of hours worked are taken from the Total Economy Database from Groningen Growth and Development Centre (http://www.ggdc.net). R&D data are used from the OECD Main Science and Technology Indicators. Patent data originate from the US Patent and Trademark Office (USPTO): 'Historic Patents by Country, State, and Year – Utility Patents (December 2003), Granted: 01/01/1963 – 12/31/2003' (http://www.uspto.gov). The business ownership rate was computed using data from the Compendia dataset of EIM Business and Policy Research (http://data.ondernemerschap.nl). The data for average years of education originate from the study by Bassanini and Scarpetta (2001, 2002). The sector composition variable is based on data from the OECD STAN database. Data concerning taxes are obtained from the OECD Revenue Statistics database. In the remainder of this section we provide some additional information about the construction of our dependent TFP variable, our R&D variables, the catching-up variables, the entrepreneurship variable and the variable concerning the openness of the economy.

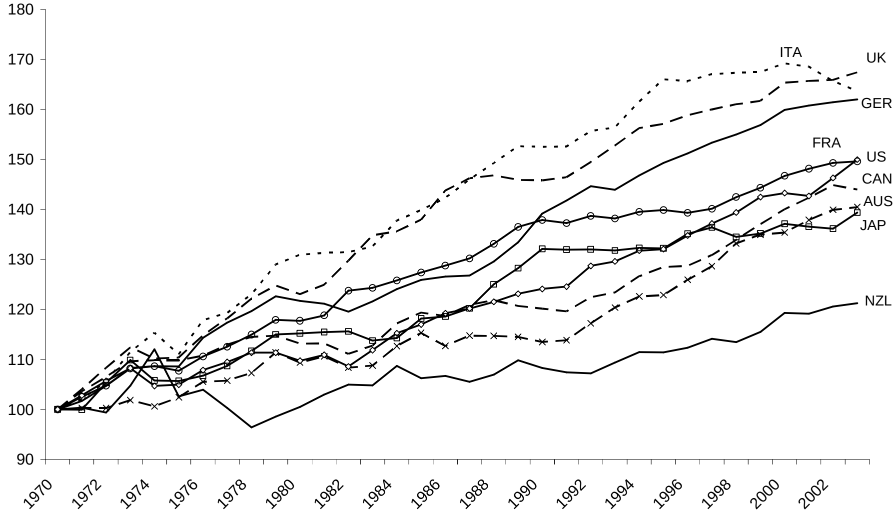
9.4.1 Total factor productivity (TFP)

TFP is an index of total factor productivity of firms computed in the conventional way as a ratio of gross domestic product of firms (volume) and a weighted sum of hours of labour and capital of firms, all expressed as indices.[178] Abstracting from the impact of human capital and using the conventional weights for capital and labour (Section 9.2), $TFP = Y/(K^{1/3} \cdot L^{2/3})$.

Figures 9.1 and 9.2 show the development of total factor productivity for the countries included in the study. Ireland shows a remarkable rise of TFP levels over time, whereas in Switzerland the level of total factor productivity grew hardly over time. Other countries which experienced a relative high growth of TFP are Norway and Finland in contrast to their Nordic neighbour Denmark. Finally, Anglo-Saxon countries like the UK, Australia, Canada and the US demonstrate a steep rise of TFP levels during the 1990s in particular.

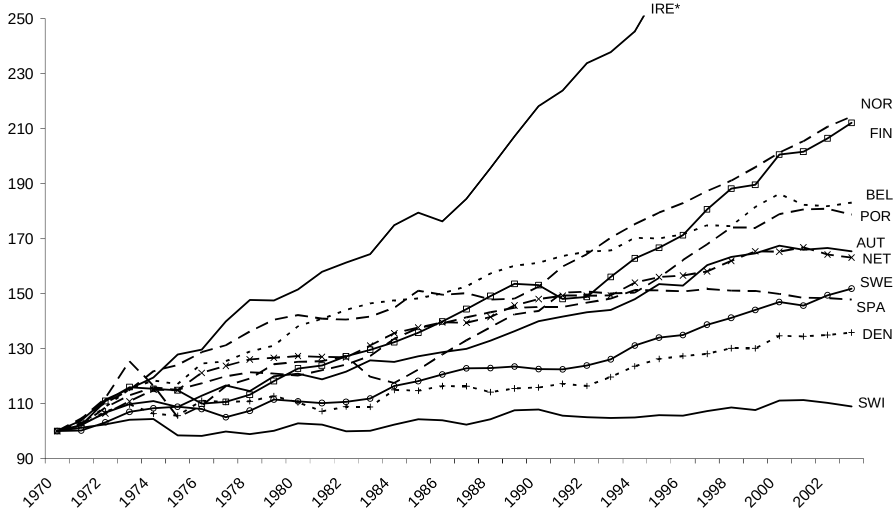
[178] For the R&D variables it is conventional and necessary to use indices. Hence, for uniformity we also applied the index approach to all other variables.

Figure 9.1 Development of TFP per hour worked in levels for large EU countries and non EU countries, 1970 = 100



Source: own calculations based on OECD Economic Outlook database.

Figure 9.2 Development of TFP per hour worked in levels for a selection of small OECD countries, 1970 = 100



Source: calculation based on OECD Economic Outlook database.

* Due to the explosive development of TFP in Ireland, data are not plotted beyond 1994. In 2002, the TFP index of Ireland was approximately 371. See also Burke (1996).

9.4.2 R&D capital

Volumes of R&D capital are calculated with a separate R&D deflator. In line with Coe and Helpman (1995, p. 878), nominal R&D expenditure is deflated using the following index for the price of R&D: $PR = P^{0.5} \times W^{0.5}$, where P is the deflator for domestic expenditure and W an index of overall wage development. We assume that half of all R&D expenditure consists of wage costs and that the development of wages of R&D personnel is in line with the development of wages in general.

R&D capital is calculated following Guellec and Van Pottelsberghe de la Potterie (2004). The stock at time t is equal to new R&D investments (in volumes) at time t plus the stock at t-1 minus depreciation, as shown in Section 9.3, equation (9.13). R&D expenditure data are only available for a limited number of years. Nevertheless, using some assumptions we can calculate an initial stock of R&D, as specified by Guellec and Van Pottelsberghe de la Potterie. If RD_0 represents the R&D expenditure (in volumes) of the first known year (t = 0) and we assume that R&D expenditure (in volumes) grew at a rate g in the years before t = 0, we are able to calculate our initial stock RDK_0 by the following equation:

$$RDK_0 = RD_0 + (1-\delta)\lambda RD_0 + (1-\delta)^2 \lambda^2 RD_0 + (1-\delta)^3 \lambda^3 RD_0 + ... \qquad (9.15)$$

In (15), δ is the depreciation rate of R&D capital and $\lambda = 1/(1+g)$, where g represents the growth rate of R&D expenditure. The initial stock of R&D capital equals:

$$RDK_0 = \frac{RD_0}{1-\lambda(1-\delta)} \qquad (9.16)$$

To calculate the initial R&D capital stock, the depreciation rate of R&D capital (δ) and the growth rate of R&D capital have to be known. The depreciation rate of R&D capital is set on 15%, based on Griliches (2000, p. 54), who refers to this percentage as being the *"'conventional' 15 percent figure for the depreciation of R&D-capital"*. This depreciation rate is also chosen by Guellec and Van Pottelsberghe de la Potterie. The growth rate of R&D expenditure is calculated using:

$$g = \left(\frac{X_n}{X_0}\right)^{\frac{1}{n}} - 1 \qquad (9.17)$$

In equation (9.17), X_n is the last known data point in the series of R&D expenditure and X_0 the first known. The index n represents the number of years. This method for calculating g implies that the growth rate of R&D expenditure (in volumes) in the years prior to the first-known data point for R&D expenditure is assumed to be equal to the growth rate in the years for which data are available.

9.4.3 Catching-up

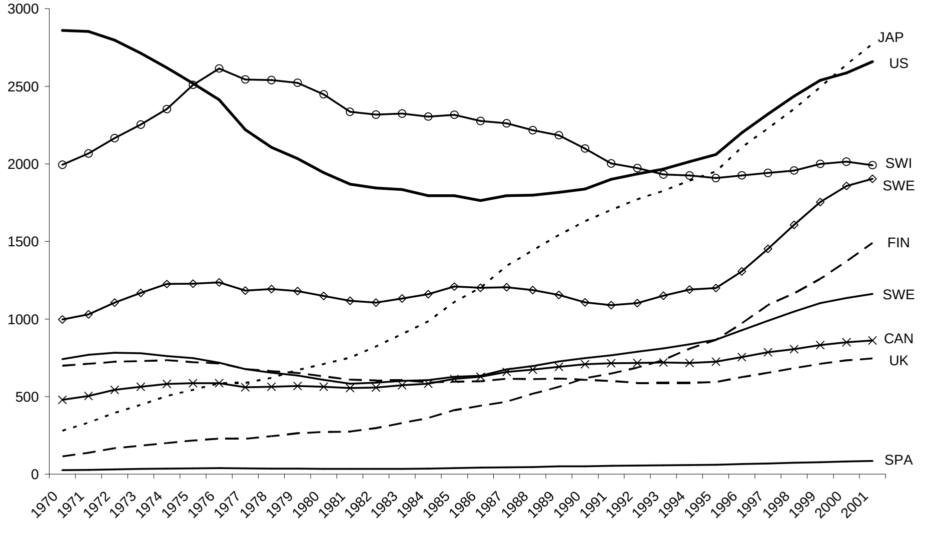
As far as we know, the use of a catching-up mechanism when explaining the development of productivity *levels* is new. Conventionally, catching-up is modelled in equations explaining the *growth* of productivity. As a consequence, we have to transform the conventional catching-up mechanism in productivity growth equations into a mechanism suitable for productivity level estimations. Our base year is 1995, which means that the value of the catching-up variable per country in this year is zero. The values for the years preceding 1995 represent the potential cumulated catching-up effects of each country towards the technological leader up till 1995, while the values for the years after 1995 represent the already realised cumulated catching-up effects in comparison with the situation in 1995.

The catching-up mechanism is constructed using the cumulated knowledge stock based on data concerning the number of patents granted by the US Patent and Trade Office in relation to the labour force. The construction of the patent knowledge stock is based on Furman *et al.* (2002) and Porter and Stern (2000). In contrast to Furman *et al.* (2002) and Porter and Stern (2000), we use a depreciation rate of 15% to take into account the obsolescence of knowledge. Furthermore, we construct an initial knowledge stock based on patents in a similar way as is conducted to calculate the series for the R&D capital stock. In addition, data is used where the number of patents granted to establishments in the US is adjusted for their 'home advantage' by selecting patents granted in at least one other country as well. Finally, based on Furman and Hayes (2004), we assume that patents are granted after a time lag of two years.[179] Figure 9.3 shows the technological position for a selection of countries based on the cumulated patent stock.

The catching-up variable is constructed by calculating the distance of a country's patent stock (in relation to the labour force) relative to the technological leader. Although both Japan and Switzerland rank high on the stock of granted USPTO patents, the US is defined as the technological leader. The relative distance towards the US in terms of the stock of granted USPTO patents indicates the catching-up potential towards the technological leader. This deviation over time, expressed as an index, is used as our catching-up variable. The natural logarithm of the country's patent stock (in relation to the labour force) relative to the technological leader is the catching-up variable that would be applicable in an equation explaining productivity growth. This variable is transformed into a catching-up variable explaining the development of productivity levels by cumulating it forwards and backwards from the reference year 1995 (thereby setting the value of the variable at 0 in this reference year).

[179] Furman *et al.* (2002) and Porter and Stern (2000) assume a time lag of three years between the development of new knowledge and the grant of a patent on this newly developed knowledge.

Figure 9.3 Technological position of countries based on accumulated stock of granted USPTO patents (in year t+2), adjusted for depreciation (15%) and expressed in relation to millions of persons of the labour force



Source: calculations based on USPTO data and data from OECD Economic Outlook database no. 75.

Next to a direct catching-up variable, which measures the distance between countries based on only the cumulated number of granted patents, we also compute a catching-up variable in which the catching-up potential is dependent on the R&D capital intensity of a country. This second catching-up variable is constructed by using the R&D capital intensity as an interaction term for the natural logarithm of the country's patent stock (in relation to the labour force) relative to the technological leader and subsequently cumulating these interacted figures forwards and backwards from the reference year 1995. The idea behind this second catching-up variable is that the larger the amount of R&D within a country (and the larger the distance between a country and the technological leader), the faster a country can catch up towards the technological leader. This variable is inspired on the Cohen and Levinthal (1989) idea of 'absorptive capacity', meaning that countries need a domestic research base in order to absorb technologies developed abroad.

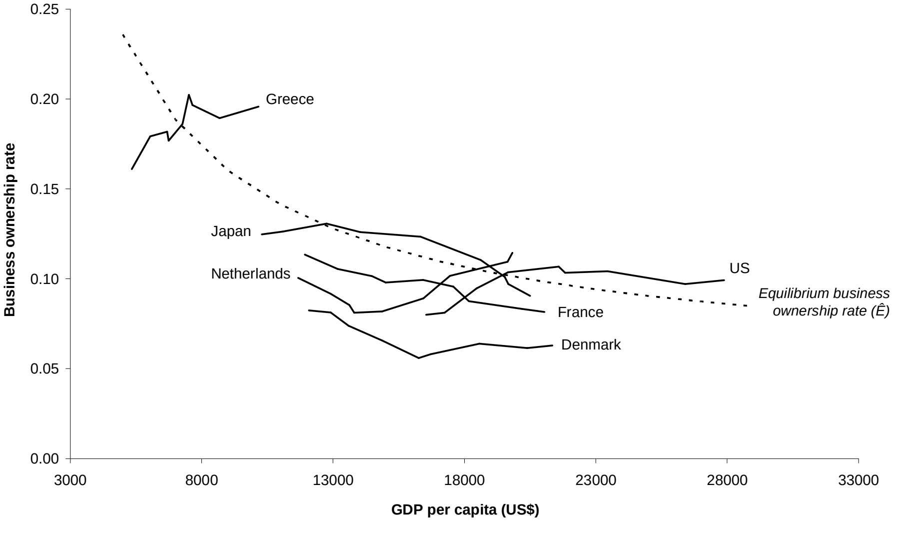
9.4.4 Entrepreneurship

Our entrepreneurship variable is based on recent work by Carree *et al.* (2007). Using long-time series for 23 OECD countries, they examine the relationship between GDP per capita and the business ownership rate. The authors find evidence for an *'equilibrium' business ownership* *rate*, given the economic level of a country, which can be represented by the following L-shaped relationship:

$$\hat{E} = \beta - \delta \frac{Y_{cap}}{Y_{cap} + 1} \tag{9.18}$$

In equation (9.18), $\hat{E}$ is the 'equilibrium' number of business owners in relation to the labour force and Y_{cap} represents GDP per capita (in thousands of $US, prices of 1990 and $PPP). Entrepreneurship gradually declines towards an asymptotic minimum value (of $\beta - \delta$). Based on the estimations by Carree *et al.* (2007), the values of β and δ can be fixed at 1.18 and 1.13, respectively. Figure 9.4 shows the 'equilibrium' business ownership rate ($\hat{E}$), substituting the estimated coefficients of β and δ in equation (9.18). Each plotted country shows the development of the actual business ownership rate over the period 1972-2004.

Figure 9.4 Business ownership and GDP per capita (US$), 1972-2004



The entrepreneurship variable used in our analyses is the ratio of the actual business ownership rate (e) and the 'equilibrium' business ownership rate ($\hat{E}$). We expect this ratio to have a positive effect on TFP.[180] Clearly, both TFP and the ratio of the actual and the 'equilibrium'

[180] The model of Carree *et al.* (2007) is different from ours, because they assume deviations from the 'equilibrium' rate to be harmful for economic growth ('growth penalty'). The authors test for asymmetries, providing evidence that a business ownership below the 'equilibrium' rate is harmful for economic growth ('growth penalty'), while

business ownership rate depend on the level of economic development (per capita income). In Annex 1 we show that the sign of $\frac{d\ln(TFP)}{d\ln\left(e/\hat{E}\right)}$ is not predetermined by their construction.

9.4.5 *Openness of the economy*

The indicator for the openness of an economy is based on the trade exposure variable used in Bassanini *et al.* (2001). This variable encompasses a weighted average of export intensity and import penetration.[181] In contrast to Bassanini *et al.* (2001), we use volumes rather than nominal values. There are two reasons. First, the price development of GDP is largely dependent on the price development in the services sector. However, the price level of services has increased more rapidly over time than prices of industrial products, principally because manufacturing productivity has increased at a faster pace. Expressing exports and imports in relation to GDP in volumes gives a more valid picture of the internationalisation development, since exports and imports consist primarily of industrial products and internationalisation is more relevant for manufacturing than for services (Van Bergeijk and Mensink, 1997). Secondly, export and import prices are dependent on short-term price fluctuations on international markets. For instance, exchange rate volatility can affect import and export prices severely (Kleinknecht and ter Wengel, 1998). By using volumes rather than nominal values, these short-term price fluctuations disappear.

In line with Bassanini *et al*. (2001), we adjust the openness variable for country size. Small countries are more exposed to foreign trade, regardless of their trade policy or competitiveness, because the share of small economies within total world economy is smaller by definition. In large countries, competitive pressure emerges mainly from domestic competition across regions. Donselaar and Segers (2006, p. 94) estimate the impact of the size of the economy on the trade exposure variable. We use these regression outcomes to adjust the trade exposure variable for country size. Annex 3 provides information how this adjustment was carried out.

9.5 EMPIRICAL RESULTS

We adopt a two-step cointegration approach which will be explained in Section 9.5.1. Section 9.5.2 presents the main results of our TFP estimations. These estimations encompass the long-run equilibrium relationship, which is step one of the cointegration approach. Next to reproducing the results of existing models, each model is extended with the entrepreneurship

a business ownership rate above the ‘equilibrium’ business ownership rate is not detrimental for economic growth. An equivalent asymmetry will be tested for in this study.

[181] Bassanini *et al*. (2001, footnote 37) use the following equation to calculate the trade exposure variable: $TRADE = X_i + (1 - X_i) \times M_p$. In this equation X_i represents the ratio of exports in relation to GDP. M_p is the ratio of imports in relation to apparent consumption. The apparent consumption is calculated by domestic production minus exports plus imports.

variable. Subsequently, we combine the models into one comprehensive ‘all in the family’ model. In Section 9.5.3 the results of dynamic correlation models are presented. These models expose the short-term dynamics between total factor productivity and the independent variables. At the same time, we are able to test for cointegration using these short-term error correction models. Finally, in Section 9.5.4 we interpret some of the estimation results.

9.5.1 Cointegration approach: a two-step methodology

Obtaining spurious results is a serious risk when using panel data analysis with a long temporal component, because the dependent and most independent variables are trended over time (Granger and Newbold, 1974). This risk is prominent when variables are non-stationary. We check whether our variables are stationary using augmented Dickey-Fuller (ADF) tests (Dickey and Fuller, 1979, 1981). Table 9.2 shows the ADF test of our dependent TFP variable.

The t-values in Table 9.2 can be interpreted using Levin and Lin (1992) where critical t-values for panel data are given. The critical t-value in case of 620 observation amounts to -7.07, while the t-value of the lagged level of our dependent variable is -4.28. We have to conclude that our dependent variable is non-stationary. Applying Dickey-Fuller tests to other important independent variables, such as the R&D variables and our entrepreneurship variable, show that these variables are non-stationary as well.

Table 9.2 ADF test on dependent variable (total factor productivity)

	Δln(*TFP*)
Constant	-0.00 (-0.60)
Level of variable TFP, lagged one year	-0.05 (-4.28)
Trend	0.00 (2.87)
Delta of variable TFP, lagged one year	0.14 (3.44)
Country dummies	Yes
Adjusted R^2	0.13
Durbin-Watson (D.W.)	1.95
Number of observations (N)	620

Taking first differences of variables is a safe option to prevent the danger of spurious regression results when estimating relations between trended variables (Wooldridge, 2003, p. 615). Unfortunately, taking first differences implies that we lose information of the long-run relationship between the levels of the variables (Greene, 2000, p. 790). If non-stationary variables are cointegrated, however, taking first differences is not necessary. Cointegration means that there exists a particular linear combination of nonstationary variables which is stationary, i.e. the residuals of the relationship are stationary in the long-run equilibrium. Hence, if series are cointegrated, their long-run equilibrium relationship can be estimated in levels (instead of differences) without running the risk of obtaining spurious results. Engle and Granger (1987) developed a two-step cointegration approach. First, the long-run relationship between variables is estimated, in our case total factor productivity and a set of independent variables. Secondly, an error correction model is estimated, which allows assessment of the short-term dynamics of our long-run equilibrium models and simultaneously check for cointegration.

It is useful to jump ahead a bit – we will return to this matter in Section 9.5.3 – and note that all estimated long-run equilibrium models in Section 9.5.2 have a cointegration vector. In addition, the estimations show a very low the Durbin-Watson statistic in each model (Section 9.5.2). This means that strong autocorrelation in the residuals occurs within the long-run equilibrium estimations, which indicates that the adjustment of the independent variables towards their long-run cointegrated equilibrium may take a long period. This autocorrelation, however, does not affect the estimated coefficients. On the contrary, OLS estimates of cointegrated time series converge to their coefficient values much faster than in case of stationary variables, making these regressions ‘super consistent’ (Stock, 1987; Verbeek, 2004, p. 316; Greene, 2000, p. 795). However, the autocorrelation does bias the standard errors, which makes the t-values unreliable. Therefore, the estimations are computed with heteroskedasticity-and-autocorrelation-consistent (HAC) standard errors or simply Newey-West standard errors (Verbeek, 2004, p. 317).

We use country dummies to take account of ‘fixed effects’. This means that solely developments over time are considered. The inclusion of country dummies prevents estimation bias due to unobserved heterogeneity (Wooldridge, 2003, p. 439). In some of the models we also use time dummies in order to absorb time-specific exogenous shocks. All estimations adopt a log-linear functional form. The variables are computed as indices using 1995 as our base year (1995 = 1). Tests show that expressing the variables in indices does not affect the estimated coefficients of the variables.

9.5.2 Step 1: estimating long-run cointegration relationships

Table 9.3 shows the OLS estimation results of the long-run relationships. We re-estimate the models introduced in five influential studies on the drivers of productivity development (Coe and Helpman, 1995; Engelbrecht, 1997; Guellec and Van Pottelsberghe de la Potterie, 2004; Griffith *et al.*, 2004; Belorgey *et al*., 2006) using one data set and extend these models with entrepreneurship. Moreover, results are presented of an ‘all in the family’ equation (all drivers of the five approaches plus controls). Annex 5 provides the technical aspects of each specification. An important divergence from the authentic models is that we approximate each model in levels (rather than, for instance, estimations in first differences or estimations using an error correction specification).[182] As a consequence, the functional form of the reproduced models in this chapter sometimes differs from the authentic models. Although the lag structure of the variables varies throughout the different specifications, it is important to stress that we have experimented with different lag structures and the empirical results are not sensitive to changes of the chosen lag structure.

Coe and Helpman (1995)
In column (1), the coefficients are given of an equation inspired on the work by Coe and Helpman (1995, p. 869, Table 3, column (iii)). Their equation abstracts from variables other than private R&D capital variables. First, the impact of domestic private R&D capital is included independently (c_2). Secondly, the impact of domestic private R&D capital is allowed to differ between larger and smaller countries (c_5). We use a different approach than Coe and Helpman to model this '*scale effect*' of domestic private R&D. Coe and Helpman interacted the domestic R&D capital stock with a dummy variable representing the so-called G7 countries. We use a variable that differentiates between the size of countries by interacting domestic private R&D capital with the share of domestic R&D capital within worldwide R&D capital (i.e. the accumulated R&D capital stock for 20 OECD countries). This variable is different than the one used by Coe and Helpman, who simply discriminate between the G7 countries and non-G7 countries. The third variable in our equation represents the foreign private R&D capital stock interacted with the ratio of imports to GDP (c_6), thereby allowing for country-specific, time-varying elasticities on foreign private R&D that are related to trade shares (Coe and Helpman, 1995, p. 870). The estimation results show much similarity with the original results of Coe and Helpman (1995), although our coefficients of domestic private R&D capital (c_2) and foreign private R&D capital interacted with the import quote (c_6) are both higher.[183] These differences are most likely due to the fact that Coe and Helpman use a depreciation rate of 5% to calculate R&D capital, while we use a depreciation rate of 15%. Coe and Helpman also conduct estimations with a 15% depreciation rate (Coe and Helpman, 1995, Table B1, column (iii)) and as a result find higher coefficients of domestic private R&D capital. Similarly, they experiment with time dummies and the possibility of varying coefficients over time and between periods. These estimations show higher coefficients of foreign R&D capital. The coefficient of the scale effect related domestic private R&D (c_5) cannot directly be compared to the scale effect estimated by Coe and Helpman because of modelling differences. We conclude that domestic private R&D has a significant large direct impact on the development of TFP levels. Note that the scale effect related to c_4 and the impact of foreign R&D are each others counterparts: larger countries benefit more than small countries do from domestic private R&D capital, whereas small countries benefit to a larger extent from foreign private R&D capital.

[182] The 'Belorgey' model is the only exception which is estimated using so-called generalized method of moments (GMM), a dynamic panel technique.
[183] The elasticity of domestic private R&D capital is 0.18 in our estimation, whereas Coe and Helpman find an elasticity of 0.08. The coefficient related to foreign R&D interacted with the import quote in our estimated equation is 0.73, while Coe and Helpman find an elasticity of 0.29.

Table 9.3 Estimation results of long-run equilibrium relationships

Coefficients and variables		**Dependent variable: ln(*TFP*), ** = Δln(*TFP*)**												
		(1) [1]	**(2)**	**(3)** [2]	**(4)**	**(5)** [3]	**(6)** [4]	**(7)** [5]	**(8)** [6]	**(9)**	**(10)** [**, 7]	**(11)** [**]	**(12)** [8]	**(13)** [9]
c_1	Constant	*-0.03* *(-1.79)*	*-0.02* *(-1.04)*	*-0.01* *(-1.29)*	*-0.01* *(-0.70)*	*-0.02* *(-1.49)*	*-0.01* *(-0.80)*	-0.04 (-2.10)	*-0.01* *(-0.71)*	*-0.01* *(-0.58)*	*0.01* *(1.12)*	*0.00* *(1.00)*	*0.01* *(1.01)*	*0.02* *(1.90)*
c_2	Private domestic R&D capital	0.18 (5.76)	0.14 (6.41)	0.13 (4.33)	0.10 (4.54)	0.13 (3.91)	0.10 (4.12)	0.21 (3.67)	0.08 (-)	0.07 (-)	-	-	0.16 (7.53)	0.14 (-)
c_3	Public domestic R&D capital	-	-	-	-	-	-	-0.13 (-2.06)	0.07 (-)	0.06 (-)	-	-	-	0.10 (-)
c_4	Total domestic R&D capital (public and private)	-	-	-	-	-	-	-	0.15 (2.96)	0.13 (3.24)	-	-	-	0.25 (6.74)
c_5	Interaction term: R&D capital as a share of R&D capital worldwide × domestic (private) R&D capital	0.21 (1.95)	*0.16* *(1.54)*	*0.12* *(0.83)*	*0.09* *(0.75)*	-	-	-	-	-	-	-	1.03 (6.48)	1.39 (6.40)
c_6	Interaction term: import quote × (private) foreign R&D capital	0.73 (5.85)	0.51 (3.39)	0.45 (2.80)	0.32 (1.88)	-	-	0.54 (2.80)	0.70 (2.44)	0.60 (2.41)	-	-	0.63 (3.92)	0.68 (3.34)
c_7	Average duration of education	-	-	0.60 (3.73)	0.49 (3.18)	0.47 (3.34)	0.29 (1.98)	-	-	-	-	-	0.30 (2.56)	0.45 (-)
c_8	Entrepreneurship: deviation from 'equilibrium' business ownership rate	-	0.23 (3.44)	-	0.19 (3.05)	-	0.23 (3.87)	-	-	0.25 (3.00)	-	0.06 (2.47)	0.15 (4.59)	0.15 (5.68)
c_9	Catching-up mechanism	-	-	-	-	*0.000* *(0.54)*	*0.001* *(1.56)*	-	-	-	-	-	-0.001 (-2.31)	*-0.001* *(-1.32)*
c_{10}	Interaction term: catching-up × domestic R&D capital	-	-	-	-	-0.04 (-3.40)	-0.04 (-3.74)	-	-	-	-	-	-0.03 (-5.12)	-0.05 (-4.64)
c_{11}	Labour participation	-	-	-	-	-	-	-	-	-	-0.55 (-6.78)	-0.55 (-7.09)	-0.42 (-5.18)	-0.42 (-4.87)

Table 9.3 (continued)

c_{12}	Number of hours worked per employed person	-	-	-	-	-	-	-	-	-	-0.66 (-15.44)	-0.67 (-16.05)	-0.75 (-6.52)	-0.65 (-6.08)
c_{13}	Unemployment rate (Δ)	-	-	-	-	-	-	-0.01 (-3.18)	-0.02 (-3.34)	-0.01 (-2.34)	-	-	*-0.000 (-0.05)*	*-0.002 (-0.77)*
c_{14}	Sector composition (share of high-tech and medium-high-tech sectors in GDP)	-	-	-	-	-	-	-	-	-	-	-	0.12 (6.89)	0.17 (8.21)
c_{15}	Business cycle	-	-	-	-	-	-	-	-	-	0.87 (12.14)	0.85 (11.40)	0.89 (6.85)	0.80 (5.63)
c_{16}	Capital income share	-	-	-	-	-	-	-	-	-	-	-	0.08 (3.56)	0.06 (2.91)
c_{17}	Burden of taxation	-	-	-	-	-	-	-	-	-	-	-	-0.10 (-1.89)	-0.16 (-2.75)
c_{18}	Openness of the economy	-	-	-	-	-	-	-	-	-	-	-	*-0.01 (-0.20)*	*-0.05 (-0.62)*
c_{19}	Autoregressive term (Y_{t-1}), lagged dependent variable	-	-	-	-	-	-	-	-	-	0.39 (2.23)	0.37 (2.05)	-	-
c_{20}	German reunification dummy (1991)	-	-	-	-	-	-	0.07 (4.77)	0.06 (4.27)	0.06 (3.38)	-	-	*0.02 (0.92)*	*0.009 (0.54)*
c_{λ}	Weight of private R&D within total R&D								0.56 (-)	0.56 (-)				0.59 (5.81)
Country dummies?		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies?		No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2		0.82	0.85	0.84	0.86	0.84	0.87	0.84	0.81	0.84	0.78	0.73	0.95	0.95
Durbin-Watson (D.W.)		0.12	0.12	0.13	0.13	0.13	0.13	0.12	0.11	0.11	1.77	1.74	0.19	0.23
N (number of observations)		620	620	620	620	620	620	620	620	620	600	600	640	620

Remarks:
The t-values are presented in brackets; standard errors have been adjusted for heteroskedasticity and autocorrelation in the residuals (Newey-West HAC standard errors). Variables with an insignificant effect on the dependent variable are presented in *italics*. All variables are expressed in natural logs, except for the unemployment rate, the interaction effects and the dummy variables. We refer to Annex 5 for the specification of each estimated model.

[1] Following Coe and Helpman, only the import quote has a lag of one year.

[2] The import quote and human capital variables are both lagged one year. Using either the lag structure of Engelbrecht (1997) – a lag of one year – or Bassanini and Scarpetta (2001, 2002) – no lags – for the human capital variable does not alter the results.

[3] The equation is not identical to the specification used by Griffith *et al.* (2004, see p. 889, Table 2, column (6)). First and foremost, the estimation of Griffith *et al.* explains productivity growth (expressed in Δ), while our model explains the development of the level of productivity. Furthermore, our private R&D variable consists of R&D capital, while Griffith *et al.* (2004) use R&D intensity. Subsequent to Griffith *et al.*, we lag all independent variables by one year.

[4] The human capital variable is lagged two years instead of one year to optimise the regression output. The other variables are lagged one year.

[5] In accordance with Guellec and Van Pottelsberghe de la Potterie (2004, Table B1 (column 4), page 375), domestic public R&D was lagged two years, whereas domestic private R&D capital and foreign private R&D capital are both lagged one year.

[6] In contrast to Guellec and Van Pottelsberghe, in the estimation in column (8) and (9) of Table 9.3 we also differentiate between public and private R&D capital when estimating the effect of foreign R&D capital (c_6). For simplification, we adopt the same artificial weights as used for private and public domestic R&D capital: respectively 0.56 (foreign private R&D capital) and 0.44 (foreign public R&D capital). Furthermore, for foreign R&D capital the same lags were used as for domestic R&D capital, meaning that foreign private R&D capital is lagged one year and public foreign R&D capital two years.

[7] We include only the significant variables from the baseline equation of Belorgey *et al.* (2006): change in hours worked, change in employment rate and an indicator to take into account the impact of the business cycle. Similar to the equation by Belorgey *et al*. (2006), each variable is specified in delta logs (Δ). The estimation is conducted using GMM methodology, where we use the lagged levels of *TFP* ($TFP_{i,t-2}$ and $TFP_{i,t-3}$) as instruments for the delta lagged dependent variable $\Delta TFP_{i,t-1}$ (see Greene, 2000, pp. 583-584). We use an alternative business cycle variable compared to Belorgey *et al.* (see Section 9.3.5). In their equation, Belorgey *et al.* also find a significant effect of the investment ratio, capturing the impact of capital deepening on the value added of persons employed. We do not separately need to take into account the impact of capital deepening, because this effect is already adjusted for when using total factor productivity as an productivity indicator.

[8] The following variables are lagged one year: private R&D capital, the scale effect related to c_5, the complete interaction term related to c_6, the human capital variable, the catching-up variables, the sector composition variable and the capital income share.

[9] We use a different lag structure than was used in column (12). See Annex 5 for more information on the technical details, also with respect to the lag structure of each estimated model. The difference in lag structure results in 20 observations less. Adopting different lag structures, as is the case with the other estimation results, does not seriously affect any of the estimation results. In the estimations of column (8) and (9), the weights of private R&D capital (c_λ) and public R&D capital ($1-c_\lambda$) within the effect of total R&D capital (coefficient c_4) were fixed *ex ante* at respectively 56% and 44%. In column (13), the weight of private R&D capital, and public R&D as a complement, was determined empirically. This means that coefficient (c_λ,) was estimated unrestrictedly (coefficient: 0.59, t-value: 5.81) within the impact of total R&D capital (c_4). We also applied these weights on the interaction terms related to c_5 and c_6. See equation (A.27) in Annex 5 for the exact specification of column (13).

In column (2) of Table 9.3, the 'Coe and Helpman' specification is estimated including our entrepreneurship variable (c_8). The entrepreneurship variable shows a significant impact on the development of total factor productivity. Although the results with entrepreneurship in the specification do not seriously differ from the initial results in column (1), adding entrepreneurship to the model does result in a drop of the coefficients related to private domestic R&D capital and private foreign R&D capital. In addition, the domestic private R&D scale term (c_5) fails to show a significant impact on our independent variable (when entrepreneurship is included in the specification).

Engelbrecht (1997)

Engelbrecht extended the work of Coe and Helpman by introducing human capital as a driver of total factor productivity. Following Engelbrecht (1997), in column (3) of Table 9.3 human capital is incorporated in the 'Coe and Helpman' specification.[184] The estimated coefficient of 0.60 is higher than the output elasticity of 0.14 found by Engelbrecht (1997, p. 1485, Table 2, column (ii)). However, we use different high-quality data for the human capital variable: data for the average years of education of the working-age population from Bassanini and Scarpetta (2002, 2001) (see Section 9.3). Engelbrecht (1997) uses data for the average years of education (of the labour force) from Barro and Lee (1993). The magnitude of the other estimated coefficients is similar compared to the 'Coe and Helpman' specification (column (2) in Table 9.3).

Column (4) shows the estimation results of the 'Engelbrecht' equation with entrepreneurship added in the specification. In this equation, entrepreneurship again has a significant and strong effect on the development of total factor productivity. Although showing a slight fall in magnitude, the R&D variables (c_2 and c_6) remain stable and tend towards the elasticities found in the article by Coe and Helpman (1995).[185] The estimated coefficient for human capital of 0.49 is largely in accordance with the value of approximately 0.45 that we derived in Section 9.2. Also, it is in line with the result found by Bassanini and Scarpetta (2001, 2002) (Section 9.3).

Griffith, Redding and Van Reenen (2004)

In column (5) we estimate a catching-up model inspired by Griffith *et al.* (2004, p. 889, Table 2, column (6)). The independent variables include domestic private R&D capital (c_2), human capital (c_7), a direct catching-up variable based on the distance in the stock of USPTO patents granted to a country relative to the US (c_9) and a second catching-up variable encompassing the direct catching-up variable multiplied with the R&D capital intensity prior to accumulation (c_{10}). As discussed in Section 9.4, our catching-up variables are constructed using a different

[184] Conform Engelbrecht (1997, p. 1481), we lag our human capital variable by one year; see Annex 5 for the exact specification.

[185] Using a one-sided t-test with a 95% confidence interval, the critical t-value to reject the hypothesis that no significant correlation exists between a dependent and independent variable lies at 1.65 (with 620 observations). Therefore, we can not reject the hypothesis that no significant relationship exists between our TFP variable and the R&D variable related to c_6.

method when compared to the conventional catching-up variables based on productivity divergences. The major difference is that the catching-up variables used in this study are suitable for estimations in levels rather than first differences. The latter form is used by Griffith *et al.* (2004). Furthermore, problems with interference of differences in hours worked between countries on the catching-up variables, as discussed in Section 9.3, are circumvented by using catching-up variables based on patent data instead of productivity divergences. As opposed to Griffith *et al.*, we do not include a catching-up variable interacted with human capital, because this variable disturbs the effect of the direct human capital variable.

Column (5) of Table 9.3 shows the initial results of the 'Griffith' equation. Our results correspond largely to the results of Griffith *et al.* (2004). The direct catching-up variable does not show a significant negative effect, but the catching-up variable interacting with R&D capital intensity does. This means that domestic R&D capital is important for technological laggards to reduce their technological shortfall vis-à-vis the technological leader.[186] The idea is that catching-up with the technological leader is easier for a country if it has a larger research absorptive capacity, in our case measured by R&D capital. Furthermore, private R&D capital and the human capital variable show the expected coefficients. In column (6) entrepreneurship is added to the 'Griffith' model. As is the case in the 'Coe and Helpman' and 'Engelbrecht' equations, adding entrepreneurship does not affect the other outcomes (although the effect of the human capital variable declines, see footnote 185) and again proves to have a significant impact on the development of total factor productivity levels.

Guellec and Van Pottelsberghe de la Potterie (2004)

In column (7) of Table 9.3 we show the initial estimates of the 'Guellec and Van Pottelsberghe' specification (equation (A.21) in Annex 5). The impact of domestic public R&D capital on TFP is introduced in this specification. The change of the unemployment rate and a dummy variable representing the German unification in 1991 are used as controls. A distinction between our specification and the one used by Guellec and Van Pottelsberghe (2004) is that, where they estimate the direct impact of foreign private R&D capital on TFP (with a one year lag), in our estimation the foreign private R&D capital variable interacts with the import share lagged one year. Although the effect of domestic private R&D capital and foreign private R&D capital on TFP is in accordance with Guellec and Van Pottelsberghe (positive and significant), domestic public R&D capital shows a significant negative impact on R&D. This is a fundamental difference in comparison to the results from Guellec and Van Pottelsberghe, but corresponds with estimation results by Khan and Luintel (2006, p. 24, Table 2, columns 4 and 5; Table 3, column 3) and Bassanini *et al.* (2001, p. 32, Table 32, column 3). Bassanini *et al.* attribute the negative impact of public R&D on TFP to non-complementarity between public and private R&D. This means that private R&D initiatives would be crowded out by public R&D. However, further analysis shows that the negative impact of public R&D on TFP is most likely a statistical

186 In Griffith *et al.* (2004), the t-value of the direct catching-up variable is -0.62 (insignificant effect), while their catching-up variable interacted with R&D intensity shows a t-value of -2.33 (significant effect).

artefact. The variance of private and public R&D capital series are overlapping to a large extent (> 90%), which causes multicollinearity in a simple specification like the one estimated in column (7) of Table 7.3. It is beyond the scope of this chapter to investigate the consequences of multicollinearity in the simple 'Guellec and Van Pottelsberghe' model. In a more elaborate specification, however, we will try to estimate public and private R&D collectively again, when we discuss the results of our 'all in the family model'. For now, the 'Guellec and Van Pottelsberghe' model is estimated with fixed weights. The weights of R&D are derived from Guellec and Van Pottelsberghe (2004, p. 375, Table B1, column 4): business R&D and public R&D have coefficients of 0.10 and 0.08, respectively. In order to set the weights of public and private R&D capital, the coefficient $c\lambda$ is fixed at 0.56. This implies that public R&D is given a weight of 0.44 ($1- c\lambda$).

Column (8) of Table 9.3 presents the estimation of the 'Guellec and Van Pottelsberghe' model, where the weights of private R&D and public R&D capital within total R&D capital are fixed on respectively 0.56 and 0.44. The specification of the model that uses these fixed weights of public and private R&D is presented in Annex 5, equation (A.22). A separation between foreign private and public R&D capital is applied as well on the interaction term concerning foreign R&D capital and the import quote (c_6). For simplicity, we adopt the same weights that are used to separate the effects of home private and public R&D capital. The coefficient of the total R&D capital variable is 0.15. Based on the weights given *a priori*, we conclude that private R&D capital has a coefficient of 0.08 (56% $\times$ 0.15) and public R&D is given a coefficient of 0.07 (44% $\times$ 0.15). Column (9) of Table 9.3 shows the adjusted 'Guellec and Van Pottelsberghe' model including entrepreneurship. Entrepreneurship shows the expected positive impact on our productivity variable. The estimated effects of the other variables are approximately equal to the coefficients estimated in the model without entrepreneurship.

Belorgey, Lecat and Maury (2006)

In column (10), labour participation and hours worked are introduced as explanatory variables of productivity. The specification is based on Belorgey *et al.* (2006), who also include a variable capturing the effect of the business cycle and an autoregressive term. Estimating their specification in levels, however, shows unsatisfactory results. Therefore, we estimate an equation in delta logs using 'generalized method of moments' (GMM) methodology, which is the methodology chosen by Belorgey *et al.* as well (2006, page 155, Table 1, baseline equation).[187]

Both participation variables show a significant negative effect on the development of TFP levels.[188] The variable hours worked has a stronger effect on productivity (long-run elasticity of -0.42) compared to the participation variable (long-run elasticity of -0.35), whereas in Belorgey

[187] For some literature on GMM methodology, see Hall (2005), Blundell and Bond (2000), Greene (2000, p. 582 ff).
[188] Using different GMM specifications does not seriously alter the estimation results. These empirical sensitivity analyses are available on request with the authors.

et al. (2006) the participation variable (employment share) shows a higher negative coefficient (-0.50) compared to the variable hours worked (-0.37).[189] The magnitudes of the estimated effects are nevertheless remarkably similar (see also Donselaar and Segers, 2006; Bourlès and Cette, 2007). In column (11), our entrepreneurship variable is introduced in the 'Belorgey' equation. As was the case in the other models, entrepreneurship has a significant (although lower than elsewhere) positive impact on total factor productivity and does not disturb the coefficients of the other variables.

Complete model: 'all in the family'

In column (12) of Table 9.3, we bring all mechanisms from the previously estimated models together with some new controls: the sector composition (c_{14}), the business cycle (c_{15}), the capital income share (c_{16}), the burden of taxation (c_{17}) and the openness of the economy (c_{18}).[190] We exclude public R&D capital as a separate driver of productivity in this model, because of initial problems with the public R&D variable in the 'Guellec and Van Pottelsberghe' specification (column (7) in Table 9.3).

All previously introduced mechanisms (R&D, human capital, entrepreneurship, catching-up and labour participation) show significant and expected effects on the development of total factor productivity. The major exception concerns the coefficient related to the interaction term for domestic private R&D-capital (c_5), which is a scale effect of the share of domestic R&D capital within worldwide R&D capital. In comparison to the coefficient in the 'Coe and Helpman' and 'Engelbrecht' specification (columns (2) and (4) in Table 9.3), the size and significance of this interaction effect increases substantially. The main reason behind the rise in magnitude of the interaction effect (c_5) is the inclusion of this scale variable in combination with the catching-up variables. Through catching-up, technological laggards can continuously improve their productivity performance compared to the technological leader. If no mechanism is modelled which counteracts the catching-up mechanism, the productivity level of the technological leader will be necessarily equalled by other countries after a certain period of time. The only way that technological leaders (for instance the US) can maintain their technological leadership is if they gain exceptional productivity improvements through a scale effect linked to their own R&D efforts (which is the interaction effect related to c_5). In fact, we see that, despite rapid technological catching-up towards the US, the US somehow manages to ensure its technological leadership.

Some control variables show a significant impact on the development of TFP. The sector composition variable has a significant positive effect, which means that a higher share of high- and medium-tech industries within the economy (in relation to the R&D capital intensity) has a

[189] The elasticities of both labour endowment variables are calculated by taking the effect of the autoregressive term c_{19} into account. The elasticity of hours worked becomes (1/(1-0.37) × -0.67) = -0.42 and the elasticity of the employment ratio is: (1/1-0.37) × -0.55) = -0.35.

[190] Equation (A.26) in Annex 5 shows the specific model.

positive impact on total factor productivity. The idea is that the sector composition is of importance for the exploitation of knowledge creation through, for instance, R&D activities. Similarly, the business cycle and the capital income share show significant positive effects. The impact of the business cycle implies that deviations from a trended development of value added of businesses have a strong impact on total factor productivity development. In addition, the significant impact of the capital income share indicates that profitability of firms is important for their productivity. Tested one-sided, the burden of taxation shows the expected negative impact on productivity. Lastly, as opposed to results from Edwards (1998), we do not find a significant separate impact of the openness of the economy on productivity.

In column (13), we estimate the same equation as in column (12) with the exception that we now separately model the effect of domestic public R&D capital and foreign public R&D capital (see equation (A.27) in Annex 5 for the exact specification of our complete model). In our 'all in the family model' the impact of total domestic R&D is captured by coefficient c_4. The separate elasticities for private and public R&D capital can be derived by using the estimated weights of private (c_λ) and public R&D ($1-c_\lambda$) and multiplying these weights with the estimated coefficient for the effect of total domestic R&D capital c_4. The coefficient attributed to total R&D capital in our final model is estimated at 0.25 and the weight of private R&D capital is estimated at 59% (as indicated by the c_λ coefficient). This implies that the elasticity for the effect of private R&D capital can be determined at 0.14 (= 59% × 0.25).[191] Consequently, the weight of public R&D capital is 41%, which leads to an elasticity of the effect of public R&D on productivity of 0.09 (= 41% × 0.25). The multicollinearity problem between private and public R&D capital of the simple 'Guellec and Van Pottelsberghe' specification (column (7)) does not occur in our complete model. Apparently, the more comprehensive model of TFP in this equation, as reflected by the much higher R^2 (0.95 as opposed to 0.84 in column (7) in Table 9.3), enables to estimate separate effects of public and private R&D capital. Both public and private R&D have a significant positive impact on the development of total factor productivity.

For simplicity, we assume that the weights of foreign private R&D capital and foreign public R&D capital within the effect of total foreign R&D capital on TFP are equal to the weights of domestic private R&D capital and domestic public R&D within the effect of total domestic R&D capital.[192] The weights of foreign public and private R&D capital are similar to the weights used to separate the impact of domestic private R&D capital (c_λ) and public R&D ($1-c_\lambda$) (equation (A.27) in Annex 5). We fixed the elasticity of the human capital variable c_7 at 0.45. Due to (negative) correlation of the human capital variable with hours worked, the value of this elasticity drops when estimated together with an effect of hours worked. We fix the elasticity at

[191] The elasticity is slightly lower than 0.15, because the exact estimated coefficient is 0.245.

[192] As was the case in the estimations presented in columns (8) and (9) in Table 9.3, a distinction between foreign private and public R&D capital is applied on the interaction term related to the impact of foreign R&D capital (c_6).

0.45, which is derived in Section 9.2.1 of this chapter and which is in accordance with empirical results by Bassanini and Scarpetta (2002). The coefficients of the other variables in our complete model are approximately similar to the ones in column (12).

Despite the 'competition' from the many drivers of productivity, our entrepreneurship variable again has a significant influence on the development of TFP. The t-value of the coefficient is even higher than in any of the other 'partial' specifications.

Conclusion

The estimations presented in Table 9.3 show that entrepreneurship has a positive impact on the development of total factor productivity levels irrespective of the specification chosen. The development of deviations from the 'equilibrium' business ownership rate (Carree *et al.*, 2007) is used to capture entrepreneurship.

9.5.3 Step 2: short-term dynamics and cointegration tests

To study the short-term dynamics of the long-run relationships in section 9.5.2 and simultaneously test for cointegration, we use the following error correction model:[193]

$$\Delta \ln(TFP_t) = \alpha\Delta \ln(TFP_{t-1}) + \beta\Delta \ln(TFP^*) + \varphi\left[\ln(TFP_{t-1}) - \ln(TFP_{t-1}^{\ \ *})\right] \qquad (9.19)$$

Equation (9.19) describes the variation in total factor productivity around its long-run trend in terms of the variation of the lagged dependent variable ($\ln(TFP_{t-1})$), variations of the estimated *fitted values* of the models estimated in Section 9.5.2 ($\ln(TFP^*)$) and an error correction term ($\ln(TFP_{t-1})$-$\ln(TFP_{t-1}^{\ *})$). The fitted values of the estimated long-run relationships represent the long-run equilibrium values of ln(*TFP*) within the error correction specification. Coefficient β shows the direct translation of the estimated long-run equilibrium values of a model in the actual values of total factor productivity. Coefficient φ should have a significant negative value for a model to have a cointegration vector. If ln(*TFP*) and $\ln(TFP^*)$ are integrated of order one, $I(1)$, and have a long-run relationship, there must be a force which pulls the equilibrium error back towards zero (Verbeek, 2004, p. 318). A significant negative coefficient for φ does exactly this: if, for instance, $\ln(TFP_{t-1}) > \ln(TFP_{t-1}^{\ *})$, then ln(*TFP*) in the previous period has overshot the equilibrium; because $\varphi < 0$, the error term pushes ln(*TFP*) back towards the equilibrium (see Wooldridge, 2004, p. 621). In general, if a dependent variable *Y* and a vector of independent variables *X* have an error correction specification, then conversely the Granger representation theorem (Granger, 1983; Engle and Granger, 1987) on cointegration holds, which means that series are necessarily cointegrated (Verbeek, 2004, p. 319; Greene, 2000, p. 793). Finally, a lagged dependent variable is included in the error correction specification (denoted by

[193] The 'Belorgey' model is not a long-run steady-state model, because the estimation specification is in delta logs. Therefore, this model will not be included in the second step of the cointegration approach.

coefficient α) to take into account a *gradual* adjustment of the estimated long-run values towards the actual TFP values.[194]

Table 9.4 shows the results from the estimated error correction model of our final ('all in the family') model with and without public R&D (columns (12) and (13) in Table 9.3).

Table 9.4 Error correction specification of final model: $\Delta\ln(TFP)$

Coefficients and variables		**Column (12)**	**Column (13)**
α	$\Delta\ln(TFP_{t-1})$	*0.06* *(1.14)*	*0.06* *(1.04)*
β	$\Delta\ln(TFP^*)$	0.81 (18.34)	0.78 (15.50)
φ	$\ln(TFP_{t-1}) - \ln(TFP_{t-1}^*)$	-0.06 (-2.95)	-0.07 (-2.87)
Country dummies		No	No
Adjusted R^2		0.64	0.59
Durbin-Watson (D.W.)		1.66	1.74
Number of observations		620	600

The t-values are presented in brackets; standard errors have been adjusted for heteroskedasticity and autocorrelation in the residuals (Newey-West HAC standard errors). Because of difference in lag structure between the two models, column (13) has 20 observations less than the model estimated in column (12).

Coefficient α is insignificant, which means that the estimated long-run values of the model do not gradually adjust towards the actual TFP values, but converge at a much faster pace. Coefficient β indicates what percentage of the estimated long-run equilibrium values filters through directly in productivity changes. In the final model, approximately 80% of changes in the chosen set of variables will translate directly into productivity changes in the short term. Coefficient φ shows a significant negative effect of -0.06 and -0.07, which means that both models have a cointegration vector.

In Table 9.5, the error correction model is used to study the robustness of the other long-run equilibrium models from Table 9.3. Table 9.5 shows that each model passes the cointegration test: φ has a significant negative effect. In addition, the direct translation of a change in the long-run steady-state values of each model into the actual/trended development of productivity

[194] A lagged dependent variable is also referred to as a *Koyck lag* or *Koyck transformation* (Seddighi *et al.*, 2000, p. 132 ff). This method involves the introduction of an infinitely decreasing geometric progression: the effect of a mutation of one of the independent variables on the dependent variable is only fully realised after an infinite number of periods. In other words, the Koyck lag implies a geometrically declining effect of the past on current events. The speed with which this transformation process takes place depends on the size of the Koyck coefficient (α in equation (9.19)): the higher the coefficient (the closer to 1), the longer the transformation process will take.

is high (β), ranging from 64% to 88%. A difference with the estimations in Table 9.4 is that the lagged dependent variable (α) has a significant role in the error correction models presented in Table 9.5.

Table 9.5 Error correction models estimations

Coefficients and variables		Coe & Helpman	Coe & Helpman*	Engel-brecht	Engel-brecht*	Griffith *et al.*	Griffith *et al.**	Guellec &Van Pottels-berghe	Guellec & Van Pottels-berghe*
α	$\Delta\ln(TFP_{t-1})$	0.28 (6.14)	0.22 (5.08)	0.24 (5.31)	0.19 (4.27)	0.23 (4.90)	0.17 (3.76)	0.20 (3.69)	0.16 (3.28)
β	$\Delta\ln(TFP^*)$	0.69 (8.55)	0.79 (9.86)	0.79 (8.87)	0.88 (10.06)	0.71 (8.15)	0.83 (10.69)	0.64 (9.71)	0.73 (11.92)
φ	$\ln(TFP_{t-1}) - \ln(TFP_{t-1}^*)$	-0.10 (-5.30)	-0.11 (-5.32)	-0.10 (-4.02)	-0.10 (-4.07)	-0.07 (-2.45)	-0.07 (-2.79)	-0.07 (-2.39)	-0.07 (-2.81)
Country dummies		No	No	No	No	No	No	No	No
Adjusted R^2		0.15	0.23	0.15	0.23	0.08	0.19	0.21	0.29
Durbin-Watson (D.W.)		1.97	1.90	1.93	1.87	2.01	1.94	2.12	2.01
Number of observations		600	600	600	600	600	600	600	600

The t-values are presented in brackets; standard errors have been adjusted for heteroskedasticity and autocorrelation in the residuals (Newey-West HAC standard errors).

* Indicates that the same specification has been used including entrepreneurship.

9.5.4 Interpretation of estimation results

In this section we will only deal with the interpretation of the coefficients of the 'all in the family' specification (column (13) in Table 9.3). The coefficients of the human capital variable (c_7), labour participation (c_{11}), the amount of hours worked (c_{12}) and most control variables (e.g. sector composition, business cycle, capital income share and burden of taxation: c_{14} to c_{18}) can all be interpreted as direct output elasticities. The interpretation of the effects of R&D, catching-up, and entrepreneurship, however, is less straightforward. Therefore, we will discuss the interpretation of the estimated effects of these variables in the remainder of this section.

R&D

The impact of R&D can be divided into a private and a public part. In addition, we have to consider domestic and foreign R&D as separate channels. Because the variables concerning the effect of domestic and foreign R&D capital are designed as interaction variables in our models, the effects vary for each country and over time. In Table 9.6, the elasticities of domestic private and public R&D and foreign private and public R&D are presented for 20 different OECD countries concerning the years 1982 and 2002.

The table clearly shows that the elasticities of private R&D capital (domestic as well as foreign) are larger than the elasticity of public R&D capital. With the exception of Norway and Japan, the importance of foreign spillover effects for the development of total factor productivity has risen over time, in some cases even quite substantially. The coefficients concerning domestic R&D of each country largely remain constant over time. The domestic R&D capital stock of larger countries, such as Germany, Japan and the US, has a larger impact on total factor productivity than in smaller countries. The smaller countries, such as Belgium, the Netherland or Ireland, are often more open and benefit from foreign R&D capital for their TFP development to a larger extent than larger countries do. These conclusion are similar to those of Coe and Helpman (1995, p. 871 and 872).

Table 9.6 Country-specific, time-varying elasticities of R&D capital on total factor productivity, 1982 and 2002

	Domestic R&D capital firms		Domestic public R&D capital		Foreign R&D capital firms		Foreign public R&D capital	
	1982	2002	1982	2002	1982	2002	1982	2002
Australia	0.15	0.16	0.11	0.11	0.07	0.09	0.05	0.06
Austria	0.15	0.15	0.10	0.11	0.15	0.21	0.11	0.16
Belgium	0.15	0.15	0.11	0.11	0.26	0.33	0.18	0.23
Canada	0.16	0.17	0.11	0.12	0.10	0.15	0.07	0.11
Denmark	0.15	0.15	0.10	0.10	0.14	0.15	0.10	0.11
Finland	0.15	0.15	0.10	0.10	0.12	0.13	0.09	0.09
France	0.20	0.20	0.14	0.14	0.09	0.11	0.07	0.07
Germany	0.23	0.22	0.16	0.15	0.11	0.13	0.08	0.09
Ireland	0.15	0.15	0.10	0.10	0.24	0.33	0.17	0.23
Italy	0.17	0.17	0.12	0.12	0.10	0.11	0.07	0.08
Japan	0.27	0.29	0.19	0.20	0.06	0.04	0.04	0.03
Netherlands	0.16	0.16	0.11	0.11	0.22	0.24	0.15	0.17
New Zealand	0.15	0.15	0.10	0.10	0.12	0.13	0.09	0.09
Norway	0.15	0.15	0.10	0.10	0.14	0.11	0.10	0.08
Portugal	0.14	0.15	0.10	0.10	0.15	0.16	0.11	0.11
Spain	0.15	0.15	0.10	0.11	0.08	0.13	0.05	0.09
Sweden	0.15	0.16	0.11	0.11	0.12	0.16	0.08	0.11
Switzerland	0.16	0.15	0.11	0.11	0.14	0.16	0.10	0.11
UK	0.21	0.19	0.15	0.13	0.09	0.12	0.07	0.08
US	0.51	0.51	0.36	0.36	0.04	0.06	0.03	0.04

Calculations are based on data series *RDS* and *IMSH* (Table 9.1) in combination with estimation results of column (13) from Table 9.2 (coefficients c_4, c_5 and c_6) and the estimated value of c_λ of 0.59.

Catching-up

In our estimation results, the catching-up variable only has a significant impact on the development of total factor productivity when interacted with R&D capital. The construction of this variable makes the calculation of differentiated elasticities between countries and over time more complex.[195] However, to gain insight how to exactly interpret the catching-up variable, we calculated the contribution of the catching-up mechanism in each country with respect to the TFP growth data of each country. This is done by linking the estimated coefficient of the interacted catching-up variable from Table 9.3 (coefficient c_{10}) to the annual mutation of the interacted catching-up variable (CU^{RD} in Table 9.1). Because the annual TFP mutations show a volatile pattern, we choose to calculate average annual changes of TFP over three separate decades. The results are presented in Table 9.7.

Table 9.7 Contribution of catching-up to average annual TFP growth, in percentage points, 1971-1982, 1983-1992, 1993-2002

	TFP growth			Contribution of catching-up		
	1971-1981	**1982-1992**	**1993-2002**	**1971-1981**	**1982-1992**	**1993-2002**
Australia	0.9	0.5	1.8	0.9	0.7	0.8
Austria	1.6	1.7	1.5	0.6	0.5	0.6
Belgium	3.1	1.5	1.0	1.0	0.8	0.7
Canada	1.1	0.7	1.7	0.5	0.4	0.4
Denmark	0.6	0.7	1.5	0.6	0.6	0.7
Finland	1.5	1.7	3.3	0.8	0.6	0.5
France	1.6	1.4	0.7	1.1	0.7	0.8
Germany	1.7	1.6	1.1	0.5	0.2	0.4
Ireland	4.2	3.6	4.7	1.0	0.7	0.6
Italy	2.5	1.5	0.6	0.8	0.6	0.7
Japan	1.3	1.2	0.3	1.1	0.3	0.0
Netherlands	2.2	1.5	1.0	0.9	0.5	0.5
New Zealand	0.2	0.4	1.2	0.9	0.7	0.7
Norway	3.1	1.4	2.5	0.9	0.8	0.8
Portugal	2.3	1.5	1.8	0.7	0.6	1.0
Spain	1.8	1.7	0.1	0.4	0.6	0.8
Sweden	0.9	1.1	1.9	0.4	0.3	0.4
Switzerland	0.2	0.2	0.5	0.0	-0.2	0.1
UK	2.0	1.6	1.0	1.2	0.9	0.8
US	0.9	1.4	1.3	0.0	0.0	0.0

Calculations are based on data series CU^{RD} and *TFP* (Table 9.1) and the estimated coefficient of the interacted catching-up variable (c_{10}) in Table 9.3 (column (13)).

[195] See Section 9.4.3 for more information on how this variable is constructed.

Table 9.7 shows that the contribution of catching-up to annual TFP growth is substantial in most countries. In some cases the contribution is even larger than the realised TFP growth itself. However, one has to bear in mind that Table 9.7 only shows the partial contribution of just one determinant of total factor productivity. Within a more complete decomposition of TFP growth, other determinants – which can have a negative impact on TFP growth – are at play as well, such as labour participation, the number of hours worked, the business cycle and the burden of taxation. The most important conclusion is that catching-up is very important for the development of total factor productivity of countries. This is in line with previous literature on this topic (Griffith *et al.*, 2004; Bernard and Jones, 1996; Boussemart *et al.*, 2006).

Entrepreneurship

Before reporting on the interpretation of the coefficient of our entrepreneurship variable we will first describe the results of two tests. First, it is debatable whether the business ownership rate should be expressed in relation to the total labour force or relative to the labour force excluding employment in the public sector. A large size of the public sector (like in Denmark, Finland and Norway) gives less room for entrepreneurship, because labour is allocated in the public domain. Hence, we introduce an alternative entrepreneurship indicator where the number of business owners is expressed as a percentage of the labour force excluding employment in the public sector. This approach implies, however, that values of the ‘equilibrium’ business ownership rate of Carree *et al.* (2007) cannot be used. To test if adjusting the labour force for the size of the public sector has an important effect on the results, we re-estimated the equation for the ‘equilibrium’ business ownership rate using the labour force without employment in the public sector as the denominator of the business ownership rate (Annex 4). The values of the ‘equilibrium’ business ownership rate resulting from this re-estimation are used to calculate alternative values for the deviation of the business ownership rate relative to the ‘equilibrium’ business ownership rate. By and large, using these alternative values for the entrepreneurship variable does not alter the estimation results presented in Table 9.3, where we use the business ownership variable for the total economy. Second, it is not straightforward that the effect of changes of levels of entrepreneurship above the ‘equilibrium’ business ownership rate is identical to those below it.[196] Tests, however, show that the restriction that both effects are identical is not rejected. This implies that more entrepreneurship always translates in higher levels of total factor productivity.

The impact of entrepreneurship on total factor productivity cannot be directly derived from its coefficient (c_8), because our entrepreneurship variable is adjusted for the level of economic development. To simplify the interpretation of our entrepreneurship variable, we computed the cumulated effects of the development of our entrepreneurship variable on the development of the total factor productivity level in each separate country. Table 9.8 shows the results.

[196] See Carree *et al.* (2007), who also test for asymmetries, but use a different model where deviations from the ‘equilibrium’ rate are harmful for economic growth (‘growth penalty’).

Most countries have experienced a positive impact of the development of entrepreneurship on the development of total factor productivity over the periods 1971-1989 and 1990-2004. The strongest impact of entrepreneurship on TFP development is found in Ireland, where the cumulated impact amounts to roughly 10% in both periods under consideration. Countries like the US, the UK and Japan show a lower effect of entrepreneurship on TFP in the period 1990-2004 compared to 1971-1989, whereas the opposite is the case in countries like Austria, the Netherlands, Denmark and Germany.

Table 9.8 Cumulated effect of entrepreneurship on the development of productivity levels in percentages, 1971-1989, 1990-2004

	1971-1989	**1990-2004**
Australia	7.80	2.51
Austria	-0.45	5.22
Belgium	4.42	2.04
Canada	8.48	3.79
Denmark	-1.82	2.75
Finland	7.59	2.24
France	1.11	-1.24
Germany	1.94	4.62
Ireland	10.10	9.52
Italy	7.51	3.02
Japan	5.01	-2.84
Luxembourg	-3.84	-0.54
Netherlands	-0.56	6.61
New Zealand	3.72	4.45
Norway	1.81	0.80
Portugal	7.15	3.18
Spain	4.86	3.03
Sweden	1.17	3.93
Switzerland	3.49	0.97
UK	8.60	1.81
US	7.15	0.93

Calculations are based on data series *BOR* (Table 9.1) and the estimated coefficient of the entrepreneurship variable (c_8) in Table 9.3 (column (13)). *BOR* is expressed as the natural log of the ratio between the actual business ownership rate and the ‘equilibrium’ business ownership rate.

9.6 CONCLUDING REMARKS

We examine the role of entrepreneurship as a determinant of total factor productivity (TFP). A panel of averaged annual data is used of 20 OECD countries spanning the period 1971-2002 (some 640 data points). Total factor productivity is computed as the ratio between gross domestic product of firms (volume) and a weighted sum of hours of labour and capital of firms. Entrepreneurship is computed as the ratio between the actual business ownership rate (number of business owners per workforce) and the *'equilibrium' business ownership rate*. This ratio corrects for the influence of per capita income: Carree *et al*. (2007) show an L-shaped relation between the business ownership rate and GDP per capita. We reproduce the outcomes of five strands of the literature explaining TFP. In these strands variables such as private and public R&D capital, foreign R&D capital, human capital, catching-up towards the technological leader, labour participation and hours worked play important roles. In addition, entrepreneurship is taken into account to expose its importance in the different specifications. Ultimately, we combine all variables of the five specifications in one comprehensive 'all in the family' model.

Our empirical results confirm the robustness of the findings of the original models, even with entrepreneurship incorporated in the specifications. With or without entrepreneurship in the specification, R&D (private, public and foreign R&D capital), human capital, catching-up, labour participation and the amount of hours worked are all individually significant for the development of total factor productivity. Moreover, our results prove that entrepreneurship is a fundamental driver of productivity as well: it has a stable and significant impact on the development of productivity levels, independent of the model design.

We can only speculate as to why entrepreneurship has been absent in preceding longitudinal research examining the drivers of productivity. There are only two indicators that capture entrepreneurship over a long period of time: first, the self-employment rate and, secondly, derived from the first, the business ownership rate from the Compendia database (Van Stel, 2005). This indicator is strongly related to level of economic development. In this study, therefore, we use the deviation of the actual level of business ownership from an 'equilibrium' business ownership rate (Carree *et al.*, 2007) as our entrepreneurship variable.

A number of future research options are important to address. First, it is worthwhile to examine the relevance of a two equation model where productivity is a function of entrepreneurship, among other drivers, and entrepreneurship is a function of the level of economic development, among other drivers. In the setup of the present chapter we apply such a model but in a recursive fashion and with GDP per capita as the sole determinant of entrepreneurship. Simultaneous equation effects and the various determinants of entrepreneurship are not investigated. A second option for further research concerns the modelling of the catching-up variable. Ideally, the catching-up variable covers differences in cumulated TFP levels between countries. Because the amount of hours worked, however, is included in our model as a separate variable and a catching-up variable based on cumulated TFP levels would have to be adjusted for the amount of hours worked, the inclusion of both variables in one model may lead to simultaneity issues. A solution in this case could be to *ex ante* adjust the catching-up variable for the amount of hours worked. Thirdly, if entrepreneurship is regarded as a mechanism to penetrate the 'knowledge filter' (i.e. transform knowledge into economic relevant knowledge), within our model entrepreneurship has to interact with other drivers of growth, especially R&D, in order to show its relevance for economic development. Also, in this view it is innovative rather than imitative entrepreneurship which fosters economic development. The interaction of entrepreneurship with the stocks of domestic and foreign R&D capital is already expressed in our log-linear multiplicative specification explaining the TFP level. This specification does not allow for a further fine tuning of interaction effects while our dataset does not contain separate indicators of innovative and imitative entrepreneurship. Finally, Coe, Helpman and Hoffmaister (2008) recently published a revisited version of the Coe and Helpman study from 1995. In addition to R&D variables, Coe *et al*. (2008) include several institutional variables which are absent in this study, such as legal origin and patent protection. The results from their empirical study show that institutional differences are important determinants of total factor productivity. Therefore, it would be interesting to adopt Coe *et al*. (2008) as the sixth strand of literature to be investigated.

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ANNEX 1. Testing for endogeneity

Regressing ln(*TFP*) on $\sum_i \phi_i X_i + \gamma \ln(BOR^*)$ shows γ > 0, where *TFP* is total factor productivity, *BOR** = *e/Ê*, *e* is the business ownership rate, *Ê* is the 'equilibrium' business ownership rate and X_i is a vector of independent variables. Total factor productivity depends upon gross value added per unit of labour (*y*). The 'equilibrium' business ownership rate depends upon gross domestic product per capita (Y_{cap}). Given that *y* and Y_{cap} are equal up to a multiplicative constant (employment over population), there might be an endogeneity problem.

In this annex we show that the sign of $\frac{d\ln(TFP)}{d\ln\left(e/\hat{E}\right)}$ is **not** predetermined by construction. In what follows we take Y_{cap} to be equal to *y* without loss of generality.

Total factor productivity (*TFP*) depends on gross value added (*Y*) per unit of labour (*L*) and the amount of capital (*K*) per unit of labour:

$$TFP = \frac{y}{k^{\alpha}} \tag{A.1}$$

where $y = \frac{Y}{L}$ and $k = \frac{K}{L}$.

The 'equilibrium' business ownership rate (*Ê*) in Carree *et al*. (2007) depends on gross domestic product per capita (Y_{cap}):

$$\hat{E} = \hat{\beta} - \hat{\delta}\frac{Y_{cap}}{Y_{cap}+1} \tag{A.2}$$

while actual business ownership rate (*e*) is defined to equal (*Ê*) and an estimated error term (μ):

$$e = \hat{E} + \mu \tag{A.3}$$

Moreover, we know that in (A.1) α > 0 (≈ 1/3) and in (A.2) β > 0 (≈ 1.18) and δ > 0 (≈ 1.13).

Rewriting (A.3) using (A.2), we get:

$$\frac{e}{\hat{E}} = 1 + \frac{\mu}{\hat{E}} = 1 + \frac{\mu}{\beta - \delta\frac{y}{y+1}} \tag{A.4}$$

Then, the derivative of $e/\hat{E}$ with respect to y writes as:

$$\frac{d\left(e/\hat{E}\right)}{dy} = \frac{\mu \cdot \delta}{\left(\beta(y+1) - \delta y\right)^2} \tag{A.5}$$

Hence, the sign of $\frac{d\left(e/\hat{E}\right)}{dy}$ is given by the sign of μ since $\delta > 0$.

Using (A.1), we can write:

$$\frac{dTFP}{d\left(e/\hat{E}\right)} = \frac{dTFP}{dy} \cdot \frac{dy}{d\left(e/\hat{E}\right)} = \frac{1}{k^{\alpha}}\left(\frac{d\left(e/\hat{E}\right)}{dy}\right)^{-1} \quad \begin{matrix} < \\ > \end{matrix} \quad 0 \quad \Leftrightarrow \quad \mu \begin{matrix} < \\ > \end{matrix} \quad 0 \tag{A.6}$$

So, recalling that $\frac{d\ln(TFP)}{d\ln\left(e/\hat{E}\right)} = \frac{dTFP}{d\left(e/\hat{E}\right)} \cdot \frac{\left(e/\hat{E}\right)}{TFP}$ and that $e > 0$, $\hat{E} > 0$, $TFP > 0$, we conclude that:

$$\textbf{sign}\,\frac{d\ln TFP}{d\ln\left(e/\hat{E}\right)} = \textbf{sign}\,\frac{dTFP}{d\left(e/\hat{E}\right)}, \tag{A.7}$$

We know that $e > 0$ and $\hat{E} > 0$, since $\hat{\beta} > \hat{\delta} > 0$ and $\frac{y}{y+1} < 1$. Hence, using (A.5):

$$\textbf{sign}\,\frac{d\ln TFP}{d\ln\left(e/\hat{E}\right)} = \textbf{sign}\left(\frac{d\left(e/\hat{E}\right)}{dy}\right)^{-1} = \textbf{sign}\left(\frac{d\left(e/\hat{E}\right)}{dy}\right) = \textbf{sign}\,\mu \tag{A.8}$$

and μ, being the estimated error term, has no predefined sign.

ANNEX 2. Derivation of elasticities from Belorgey, Lecat and Maury (2006)

The long-run elasticities of the employment rate and hours worked per person are not directly available in the study by Belorgey *et al.* (2006), but have to be derived. Belorgey *et al.* (2006) estimate the impact of several independent variables, including labour participation and hours worked, on value added *per person employed*. However, we would like to know the impact on value added *per hour worked*. The value added per person employed (*GDP*/*EP*) is equal to the value added per hour worked (*GDP*/*H*) multiplied by hours worked per person employed (*H*/*EP*). Belorgey *et al.* (2006, p. 155, Table 2, column 1) estimate the following equation (leaving out explanatory variables other than the autoregressive term, hours worked and the employment rate):

$$\Delta \ln\left(\frac{GDP}{EP}\right)_t = a \times \Delta \ln\left(\frac{GDP}{EP}\right)_{t-1} + [.....] + d \times \Delta \ln\left(\frac{H}{EP}\right)_t + e \times \Delta \ln(TE)_t \qquad \text{(A.9)}$$

where *GDP* is value added, *EP* indicates persons employed, *H* is total hours worked and *TE* indicates the employment rate.

Because $\frac{GDP}{EP} = \frac{GDP}{H} \times \frac{H}{EP}$, equation (A.9) can be rewritten as

$$\Delta \ln\left(\frac{GDP}{H}\right)_t + \Delta \ln\left(\frac{H}{EP}\right)_t = a \times \Delta \ln\left(\frac{GDP}{EP}\right)_{t-1} + [.....] + d \times \Delta \ln\left(\frac{H}{EP}\right)_t + e \times \Delta \ln(TE)_t \qquad \text{(A.10)}$$

This leads to the following equation:

$$\Delta \ln\left(\frac{GDP}{H}\right)_t = a \times \Delta \ln\left(\frac{GDP}{EP}\right)_{t-1} + [.....] + (d-1) \times \Delta \ln\left(\frac{H}{EP}\right)_t + e \times \Delta \ln(TE)_t \qquad \text{(A.11)}$$

The coefficients estimated by Belorgey *et al.* (2006) for *a*, *d* and *e* are 0.248, 0.477 and -0.378, respectively. To obtain long-run elasticities of labour productivity (per hour worked) with respect to hours worked and the employment rate, the impact of the autoregressive term has to be taken into account. This is done by multiplying the initially estimated coefficients by (1/(1-*a*)), which means that the long-run elasticity with respect to hours worked (*H*/*EP*) is (1/(1-0.248)×0.477)-1 = -0.37 and that the long-run elasticity with respect to the employment rate (*TE*) is 1/(1-0.248)× -0.378 = -0.50.

ANNEX 3. Openess of the economy adjusted for size

Donselaar and Segers (2006) examined the influence of the size of the economy on the openness of the economy. They use data from the OECD Economic Outlook database (no. 75) for 20 OECD countries. The results can be summarised by the following equation:

$$\ln(TRADE_{i,t}) = 3.02 - 0.23\ln\left(\frac{GDP^{h}}{GDP^{f}}\right)_{i,t} + 0.02\,TREND \tag{A.12}$$

The variable *TRADE* represents the openness of the economy in relation to the GDP. The openness of the economy is measured by the indicator *exposure to foreign trade,* developed by Bassanini *et al*. (2001, p. 25). GDP^{h} stands for the volume of GDP (millions of US$, constant prices of 1995, $PPP) in the home country. GDP^{f} represents the total volume of GDP (millions of US$, constant prices of 1995, $PPP) in the other 19 OECD countries. *TREND* is a trend variable to take consideration of the globally increased internationalisation. The indices *i* and *t* denote country and year, respectively.

From (A.12), the following relationship can be derived to adjust the openness of the economy for the size of the domestic economy relative to the total size of the foreign economies:

$$\ln(OPENECO_{i,t}) = \ln(TRADE_{i,t}) + 0.23\ln\left(\frac{GDP^{h}}{GDP^{f}}\right)_{i,t} \tag{A.13}$$

The variable OPENECO represents the openness of an economy *i* in the hypothetical situation that the volume of GDP in country *i* would be equal to the total volume of GDP in the other 19 OECD countries. Table A.1 shows the results of the adjustment of the openness variable for a selection of years.

Table A.1 Adjustment of openness of the economy for the relative size of the domestic economy

	Openness, unadjusted				Openness, adjusted			
	1970	**1980**	**1990**	**2001**	**1970**	**1980**	**1990**	**2001**
Australia	21.8	23.5	29.6	40.3	8.8	9.4	11.9	16.6
Austria	38.3	50.2	58.0	78.5	13.3	17.5	20.0	26.9
Belgium	65.8	72.8	85.0	95.8	24.3	26.9	30.8	34.3
Canada	33.8	38.2	47.8	66.3	15.6	18.0	22.4	31.4
Denmark	35.8	41.9	54.2	69.5	11.9	13.5	16.9	21.5
Finland	37.6	42.9	43.2	68.6	11.5	13.2	13.3	20.8
France	21.3	28.0	33.7	48.6	11.9	15.6	18.5	26.3
Germany	31.4	38.6	48.2	56.5	18.7	22.7	27.9	32.9
Ireland	50.9	59.9	77.2	99.2	12.8	15.6	20.3	29.2
Italy	24.8	29.2	36.9	49.8	13.6	16.1	20.0	26.4
Japan	9.7	13.0	15.0	18.3	6.2	8.6	10.1	12.0
The Netherlands	54.1	62.3	71.4	89.6	22.0	25.2	28.4	35.8
New Zealand	31.1	37.2	43.4	53.8	8.7	10.0	11.6	14.5
Norway	49.0	49.0	56.6	63.4	14.2	14.7	16.8	19.4
Portugal	35.1	34.2	48.6	61.5	10.8	10.9	15.6	19.9
Spain	15.8	21.2	29.9	53.1	7.3	9.8	13.8	24.7
Sweden	38.8	43.2	50.4	73.1	14.4	15.5	17.8	25.4
Switzerland	36.3	47.6	53.7	67.8	13.7	17.2	19.0	23.2
US	11.0	13.6	17.7	58.2	9.8	12.1	15.9	23.9
UK	31.1	37.7	43.4	26.1	17.4	20.4	23.3	31.1

Source: Donselaar and Segers (2006).

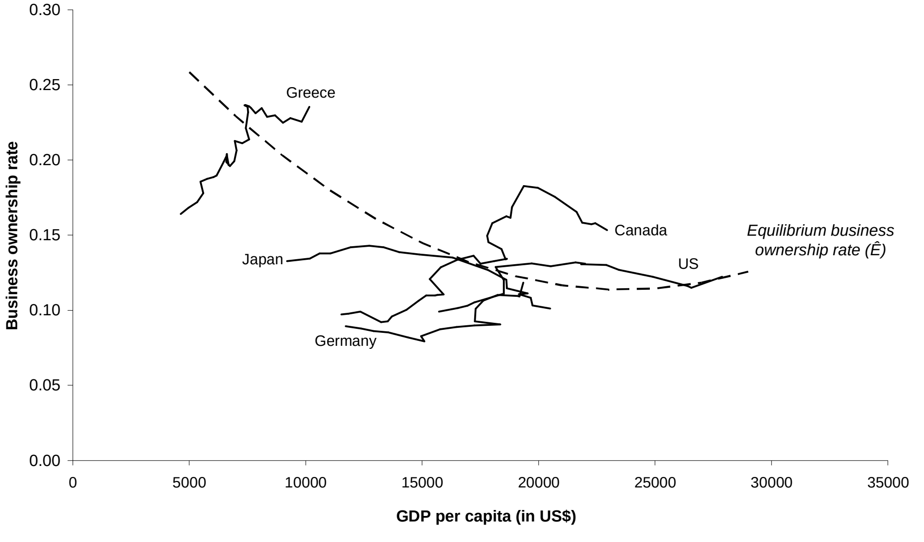
ANNEX 4. Re-estimated 'equilibrium' business ownership rate using the business ownership rate for the private sector

Our business ownership variable is measured as the total amount of businesses in a country in relation to the total labour force. Based on the methodology of Carree *et al.* (2007), we also re-estimated the 'equilibrium' business ownership rate ($\hat{E}$) using the business ownership rate for solely the *private sector*. The business ownership rate for the private sector measures the total number business ownership in relation to the labour force active within the private sector (instead of the total labour force). A U-shaped curve appears to be more suitable than an L-shaped one in explaining the relationship between the level of economic development (Y_{cap}) and the business ownership rate for only the private sector:

$$\hat{E} = \eta - \omega Y_{cap} + \vartheta (Y_{cap})^2 \qquad \text{(A.14)}$$

The values of η, ω and ϑ are estimated at 0.34, 0.02 and 0.0004, respectively. Figure A.1 shows the 'equilibrium' business ownership rate ($\hat{E}$), substituting the estimated coefficients of η, ω and ϑ in equation (A.14). Each plotted country shows the development of the actual business ownership rate over the period 1970-2004.

Figure A.1 Business ownership and GDP per capita (US$), 1970-2004



Source: EIM Compendia database.

The data on the business ownership for the private sector and equation (A.14) were used to construct an alternative entrepreneurship variable in a similar fashion as presented in Section 9.4. This alternative entrepreneurship variable is used to re-estimate the regression outcomes of Table 9.3 in Section 9.5. The results do not differ substantially from the ones presented in Table 9.3. The regression output is available upon request.

ANNEX 5. Technical aspects of estimated models

In this annex an overview is presented of the equations in Section 9.5.2, Table 9.3. The symbols in the equations are presented in detail in Table 9.1 in Section 9.4. The lags used for each variable are based on previous empirical and theoretical insights. Additional estimations show that choosing different lags only marginally affects the reported estimation results presented in Table 9.3.

Coe and Helpman

The 'Coe and Helpman' equation presented in column (1) of Table 9.3 is specified as follows:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\ RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\ imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \tag{A.15}$$

TFP is an index for total factor productivity. BRD_h represents domestic stock of private R&D capital, whereas BRD_f indicates the foreign stock of R&D. The foreign R&D capital stock is calculated based on data for the 20 OECD countries selected in this study. *RDS* denotes the share of domestic R&D capital within the total foreign R&D capital stock. The term *imsh* represents the import share. Finally, DUM_i are country dummies to take into account country-specific influences on total factor productivity.

Including the entrepreneurship variable in the 'Coe and Helpman' model (see column (2) in Table 9.3), being an index measuring the deviation from the 'equilibrium' business ownership rate (BOR^*), (A.15) becomes:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\ RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\ imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + c_8 \ln(BOR^*_{i,t}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \tag{A.16}$$

Engelbrecht

In the 'Engelbrecht' model (column (3) in Table 9.3), human capital (*HC*) as a determinant of productivity is taken into consideration. The model is estimated by means of the following equation:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\ RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\ imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + c_7 \ln(HC_{i,t-1}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \tag{A.17}$$

Incorporation of entrepreneurship in the model (see column (4) in Table 9.3), (A.17) leads to:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\, RDS_{i,t} / 100 \times \ln(BRD^h_{i,t}) + c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + c_7 \ln(HC_{i,t-1}) + c_8 (BOR^*_{i,t}) + \sum_i f_i DUM_i + \varepsilon_{i,t} \quad \text{(A.18)}$$

Griffith, Redding and Van Reenen

The general 'Griffith' equation that is estimated in column (5) of Table 9.3 is:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_7 \ln(HC_{i,t-2}) + c_9\, CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + \sum_i f_i DUM_i + \varepsilon_{i,t} \quad \text{(A.19)}$$

CU captures the catching-up mechanism as discussed in Section 9.4. CU^{RD} represents the catching-up variable in which the R&D capital intensity is included as interaction term. With entrepreneurship (column (6) in Table 9.3) (A.19) can be rewritten to:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_7 \ln(HC_{i,t-2}) + c_8 \ln(BOR^*_{i,t}) + c_9\, CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + \sum_i f_i DUM_i + \varepsilon_{i,t} \quad \text{(A.20)}$$

Guellec and Van Pottelsberghe de la Potterie

Column (7) of Table 9.3 is estimated using the following equation based on Guellec and Van Pottelsberghe de la Potterie:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_3 \ln(PRD^h_{i,t-2}) + c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t-1}) + c_{13} \Delta UR_{i,t} + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t} \quad \text{(A.21)}$$

The control variable ΔUR represents the first difference in the unemployment rate, which is intented to capture the effect of the business cycle on TFP. DUM^{91}_{GER} is a dummy variable for the German unification in 1991. This variable is 1 for Germany in 1991 and 0 otherwise. DUM_t are time dummies to take into account time-specific shocks on total factor productivity.

The specification of the model that uses the artificially imposed weights of public and private R&D (column (8) in Table 9.3) is as follows:

$$\ln(TFP_{i,t}) = c_1 + c_4 \times \left[c_\lambda \ln(BRD^h_{i,t-1}) + (1 - c_\lambda) \ln(PRD^h_{i,t-2})\right] + c_6\, imsh_{i,t-1} \times \left[c_\lambda \ln(BRD^f_{i,t-1}) + (1 - c_\lambda) \ln(PRD^f_{i,t-2})\right] + c_{13} \Delta UR_{i,t} + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t} \quad \text{(A.22)}$$

The specification used to model domestic private and domestic public R&D capital assumes that the weights of private and public R&D capital within the impact of total domestic R&D capital add up to 1.0. The weight of private R&D capital is determined by c_λ in equation (A.22). The weight of public R&D capital is derived by subtracting c_λ from 1.0. In both columns (8) and (9) of Table 9.3, c_λ is fixed at 0.56 based on estimation results of Guellec and Van Pottelsberghe (2004). This fixed coefficient for c_λ was also applied on the term related to the impact of foreign R&D capital (c_6 in equation (A.22)).

Equation (A.22) with entrepreneurship becomes:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_4 \times \left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ \ln(PRD^h_{i,t-2})\right] + c_6\, imsh_{i,t-1} \\ &\times \left[c_\lambda \ln(BRD^f_{i,t-1}) + (1-c_\lambda) \ln(PRD^f_{i,t-2})\right] + c_7 \ln(BOR^*_{i,t}) + c_{13}\Delta UR_{i,t} \\ &+ c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \quad \text{(A.23)}$$

Belorgey, Lecat and Maury

The regression equation estimated in first differences and inspired on work by Belorgey *et al.* (2006) can be formulated as follows (see column (10) in Table 9.3):

$$\begin{aligned}\Delta \ln(TFP_{i,t}) &= c_1 + c_{11}\Delta LPAR_{i,t} + c_{12}\Delta HRS_{i,t} + c_{15}\Delta \ln(BUSCYCLE_{i,t}) \\ &+ c_{19}\Delta \ln(TFP_{i,t-1}) + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \quad \text{(A.24)}$$

The labour participation variables are captured by *LPAR*, representing an index measuring the number of persons employed in relation to population, and *HRS*, which indicates the number of hours worked per person employed. TFP_{t-1} is a lagged dependent variable. *BUSCYCLE* represents the state of the business cycle, measured by the deviation of gross value added of firms from a 5-yearly moving average of gross value added of firms.

With entrepreneurship the 'Belorgey' equation changes (A.24) into:

$$\begin{aligned}\Delta \ln(TFP_{i,t}) &= c_1 + c_7\Delta \ln(BOR^*_{i,t}) + c_{11}\Delta LPAR + c_{12}\Delta HRS \\ &+ c_{15}\Delta \ln(BUSCYCLE_{i,t}) + c_{19}\Delta \ln(TFP_{i,t-1}) + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \quad \text{(A.25)}$$

As we estimate equation (A.24 and A.25) using GMM methodology, we use the lagged levels $\ln(TFP_{i,t-2})$ and $\ln(TFP_{i,t-3})$ as two instrumental variables for our lagged dependent variable $(\Delta\ln(TFP_{i,t}))$ and the other variables serve as their own instruments (see Greene, p. 584).

Complete model

The final model in which only private R&D is incorporated can be specified as:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_5\, RDS_{i,t-1}/100 \times \ln(BRD^h_{i,t-1}) + c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t-1}) \\ &+ c_7 \ln(HC_{i,t-1}) + c_8 \ln(BOR^*_{i,t}) + c_9 CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + c_{11} \ln(LPAR_{i,t}) + c_{12} \ln(HRS_{i,t}) \\ &+ c_{13} \Delta UR_{i,t} + c_{14} \times \ln\left(SECCOM_{i,t-1}/RDI_{i,t-1}\right) + c_{15} \ln(BUSCYCLE_{i,t}) + c_{16} \ln(CIS_{i,t-1}) \\ &+ c_{17} \ln(TR_{i,t}) + c_{18} \ln(OPENECO_{i,t}) + c_{20} \times DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \tag{A.26}$$

Various controls have been included in the complete model. *SECCOM* measures the share of high-tech and medium-high-tech industries in the value added of the total economy. This share is expressed in relation to total R&D capital intensity. *CIS* is an indicator of the capital income share, *TR* is the index of the tax burden expressed as total tax revenues in relation to GDP. *OPENECO* measures the openness of the economy. The composition of the openness variable is addressed in more detail in Section 9.4 of this chapter and in Annex 3. The final model with public and private R&D separated (final column (13) in Table 9.3) is somewhat more complex than equation (A.26):

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_4 \left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ln(PRD^h_{i,t-2})\right] + c_5\, RDS_{i,t-1}/100 \\ &\times \left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ln(PRD^h_{i,t-2})\right] + c_6\, imsh_{i,t-1} \times \left[c_\lambda \ln(BRD^f_{i,t-1}) + (1-c_\lambda)\ln(PRD^f_{i,t-2})\right] \\ &+ c_7 \ln(HC_{i,t-1}) + c_8 \ln(BOR^*_{i,t}) + c_9 CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + c_{11} \ln(LPAR_{i,t}) + c_{12} \ln(HRS_{i,t}) \\ &+ c_{13}\, \Delta UR_{i,t} + c_{14} \times \ln\left(SECCOM_{i,t-1}/RDI_{i,t-1}\right) + c_{15} \ln(BUSCYCLE_{i,t}) + c_{16} \ln(CIS_{i,t-1}) \\ &+ c_{17} \ln(TR_{i,t}) + c_{18} \ln(OPENECO_{i,t}) + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \tag{A.27}$$

Similarly to the 'Guellec and Van Pottelsberghe' (equation (A.22) and (A.23)), private and public R&D capital are modelled using weights for private and public R&D capital within the impact of total domestic R&D capital (c_4) that add up to 1.0. The weight of private R&D capital is determined by c_λ in equation (A.27). In contrast to the estimation of the 'Guellec and Van Pottelsberghe' model (columns (8) and (9) in Table 9.3), the estimation of the c_λ was conducted without restrictions (i.e. without fixing the weight of private R&D capital within total R&D capital *a priori*). For simplicity, we assume that the weights of foreign private R&D capital and foreign public R&D capital within the effect of total foreign R&D capital on TFP are equal to the weights of domestic private R&D capital and domestic public R&D within the effect of total domestic R&D capital. In other words, the distinction between public and private R&D capital using the estimated parameter c_λ is applied to both domestic R&D capital and foreign R&D capital (assuming the same weights c_λ and (1-c_λ) for domestic and foreign R&D capital).

Nederlandse samenvatting

Waarom dit proefschrift?

Door demografische ontwikkelingen zoals ‘vergrijzing’ en ‘ontgroening’ zullen moderne economieën, zoals de Nederlandse, steeds minder in staat zijn om economische groei te behalen uit een toenemende inzet van arbeid. Om onze welvaartsstaat ook in de toekomst op peil te kunnen houden, zal economische groei vooral via ‘slimmer werken’ ofwel arbeidsproductiviteitsgroei gerealiseerd moeten worden.[197] Tussen 1995 en 2005 was de gemiddelde jaarlijkse groei van het bruto binnenlands product (BBP) per hoofd van de bevolking in Nederland voor 85% toe te schrijven aan een hogere groei van de arbeidsproductiviteit. Voor het OESO-gemiddelde was deze groei bijna volledig het gevolg van een hogere arbeidsproductiviteitsgroei. Als arbeidsproductiviteitsgroei steeds belangrijker wordt als bron voor welvaartsgroei, dan is het tenminste zo belangrijk om de factoren van arbeidsproductiviteit helder op het netvlies te hebben. Dit proefschift is een zoektocht naar de belangrijkste determinanten van arbeidsproductiviteit. Daarbij wordt sterk de focus gelegd op het belang van Research & Development (R&D) en ondernemerschap als factoren.

Positie van proefschrift

Het proefschrift is gebaseerd op verschillende deelstudies waarin de relatie tussen arbeidsproductiviteit, R&D en ondernemerschap belicht worden. Sommige delen van het proefschrift richten zich op hiaten in de bestaande wetenschappelijke kennis, waarbij getracht wordt om nieuwe elementen toe te voegen. Zo is mede door gebrek aan data de langetermijnrelatie tussen arbeidsproductiviteit en ondernemerschap nog nauwelijks onderzocht in de literatuur. Andere delen van het proefschrift zijn meer gericht op het toepassen van wetenschappelijke kennis, vooral vanuit een beleidsmatige context. Dit gebeurt bijvoorbeeld in hoofdstuk 5, waar op basis van geschatte effecten uit de literatuur de Nederlandse R&D-achterstand ten opzichte van het OECD-gemiddelde gedecomponeerd wordt. In het algemeen krijgt de relatie tussen productiviteit en R&D in dit proefschrift meer aandacht dan de relatie tussen productiviteit en ondernemerschap.

De studies verschillen wat betreft analyseniveau – macro-, meso- en sporadisch het bedrijfsniveau – en qua type analyse – soms descriptief, soms toegepast wetenschappelijk en soms econometrisch van aard. De datasets die in dit proefschrift zijn gebruikt betreffen – met uitzondering van hoofdstuk 7 – in bijna alle gevallen grote paneldatabestanden voor op zijn minst twintig OECD-landen over meer dan dertig jaar tijd.

[197] Arbeidsproductiviteit wordt in de statistieken gedefinieerd als de toegevoegde waarde (brutoproductie minus intermediair verbruik) per eenheid arbeidsvolume. De meest relevante maatstaf om de productieve kracht van een land uit te drukken is door arbeidsproductiviteit te definiëren als de toegevoegde waarde *per gewerkt uur*.

De hoofdstukken

De inhoud van de afzonderlijke hoofdstukken wordt hieronder beschreven. In het eerste inleidende hoofdstuk wordt de relatie tussen arbeidsproductiviteit, R&D en ondernemerschap als onderwerp voor onderzoek neergezet. Er wordt vanuit maatschappelijk en wetenschappelijk perspectief belicht waarom de relatie tussen met name die drie elementen van belang is. In dit hoofdstuk wordt ook een heuristisch raamwerk gepresenteerd dat aangeeft hoe de individuele hoofdstukken in het proefschrift zich tot elkaar verhouden. Voorts wordt in dit hoofdstuk de bijdrage van dit boek besproken, er wordt een korte beschrijving per hoofdstuk gegeven, evenals de belangrijkste resultaten en conclusies.

Hoofdstuk 2

Hoofdstuk 2 behandelt de Nederlandse arbeidsproductiviteitsprestatie in internationaal perspectief. In het hoofdstuk wordt deze prestatie zowel op het macroniveau als op sectorniveau belicht. Uit de beschrijvende analyse komt naar voren dat Nederland nog steeds een van de hoogste productiviteitsniveaus ter wereld heeft. Ook de arbeidsproductiviteitsgroei kent, na een jarenlange daling, een opwaartse beweging sinds het begin van deze eeuw. Nederland heeft hiermee een uitzonderingspositie ten opzichte van het Europese gemiddelde, waar zich een duidelijke neerwaartse trend aftekent. De groei is in deze eeuw echter niet zo hoog geweest als in de VS, enkele Scandinavische landen en het OESO-gemiddelde in het algemeen. Deze landen hebben hun hoge arbeidsproductiviteitsgroei vooral te danken aan een sterke groei van de zogenoemde totale factorproductiviteit (TFP) en minder aan een sterke groei van inputfactoren per eenheid arbeid, zoals kapitaal, ICT-kapitaal of kwaliteitsverbeteringen van de productiefactor arbeid. Er is onderzocht in hoeverre werkgelegenheidsverschuivingen binnen het Nederlandse sectorlandschap een rem dan wel een stimulans zijn geweest voor de productiviteitsontwikkeling in Nederland (shift-share analyse). Hieruit blijkt dat Nederland een sterkere werkgelegenheidsverschuiving heeft gekend naar sectoren met een relatief laag arbeidsproductiviteitsniveau dan gemiddeld in de OESO het geval is. Het gaat daarbij vooral om verschuivingen van industriële sectoren naar de overige zakelijke dienstverlening.

Twee opmerkelijke uitkomsten uit het hoofdstuk zijn ten eerste dat de Nederlandse sectorstructuur geen verklaring biedt voor de achterblijvende productiviteitsgroei ten opzichte van het OESO-gemiddelde. Het is dus niet zo dat de Nederlandse groei achterblijft omdat de Nederlandse economie ondervertegenwoordigd is in bedrijfstakken met een snelle productiviteitsgroei en oververtegenwoordigd is in bedrijfstakken met een lage groei van de productiviteit. Sterker, de arbeidsproductiviteitsgroei zou lager uitpakken als Nederland eenzelfde economische structuur zou kennen als gemiddeld in de OESO. Dit komt omdat het aandeel van de groothandel, logistiek en financiële sector binnen de totale economie lager is in de OESO dan in Nederland. Deze drie sectoren zijn in Nederland verantwoordelijk geweest voor bijna de helft van de totale productiviteitsgroei tussen 1995-2005. Ten tweede lijkt ICT een minder prominente rol te spelen voor de arbeidsproductiviteitsgroei dan vaak wordt verondersteld. De bijdrage van ICT-kapitaal tussen 2000-2005 is ten opzichte van de periode 1995-2000 in vrijwel alle sectoren en landen gedaald. Ook is er geen duidelijke relatie waarneembaar tussen ICT-investeringen en totale factorproductiviteit in met name industriële sectoren. Zelfs als rekening wordt gehouden met vertragingen over de tijd is er geen patroon waarneembaar dat industriële sectoren die veel in ICT hebben geïnvesteerd een hoge TFP-groei laten zien in de periode erna. Dit resultaat wordt gestaafd door recent onderzoek van Van Ark (2006), dat laat zien dat ICT-investeringen geen supranormale rendementen opleveren.[198]

Hoofdstuk 3

Uit hoofdstuk 2 blijkt dat de totale factorproductiviteit (TFP) de belangrijkste verklaring biedt voor groeiverschillen in arbeidsproductiviteit tussen landen. Ook op sectorniveau wordt empirisch bewijs geleverd dat TFP de bepalende factor is voor de productiviteitspositie: sectoren die een sterke arbeidsproductiviteitsgroei hebben doorgemaakt, worden ook gekarakteriseerd door een sterke groei van de TFP. De logische vervolgvraag is welke factoren van invloed zijn op de TFP-ontwikkeling in landen. In hoofdstuk 3 wordt een eerste aanzet gedaan om deze vraag te beantwoorden door de determinanten van productiviteit verder te onderzoeken. Gebruikmakend van de bestaande literatuur komt naar voren dat innovatie, met als belangrijk fundament de R&D-investeringen, een belangrijke invloed uitoefent op de arbeidsproductiviteit. Berekeningen voor Nederland laten zien dat 40% van de arbeidsproductiviteitsgroei in Nederland over de jaren ’90 het gevolg is van R&D-inspanningen. Van deze 40% is 13% het gevolg van binnenlandse R&D-investeringen door bedrijven en 7% het directe effect van R&D door kennisinstellingen. De andere 20% is toe te schrijven aan R&D-inspanningen in het buitenland. De bijdrage van buitenlandse R&D-investeringen is voor een open economie als de Nederlandse dus erg belangrijk. Dit betekent overigens niet dat kleine open economieën het zich kunnen permitteren om hun eigen R&D-inspanningen op een laag pitje te brengen. Een eigen R&D-capaciteit is nodig om de vruchten te kunnen plukken van buitenlandse onderzoeksresultaten. Uit hoofdstuk 3 blijkt ook dat er sterke welvaartswinsten gemoeid zijn met een verhoging van de R&D-uitgaven: indien in Nederland de private R&D-uitgaven als percentage van het BBP zouden verdubbelen, zou dit een positief effect hebben op het arbeidsproductiviteitsniveau van 7%. Uitgaande van het BBP (marktprijzen) in 2005 komt dit neer op circa 35 miljard euro op jaarbasis.

Hoofdstuk 4

Als R&D een van de belangrijkste pijlers is van productiviteitsontwikkeling, is het interessant om deze factor nader te beschouwen. In hoofdstuk 4 wordt op basis van beschrijvende statistiek en bestaande inzichten uit de literatuur gekeken naar patronen op het gebied van bedrijfs-R&D in Nederland. R&D wordt daarbij zowel vanuit macro- als microperspectief geanalyseerd. Op macroniveau ontstaat een vrij stabiel beeld. De Nederlandse private R&D-intensiteit blijft met om en nabij de 1% al jaren achter ten opzichte van het OESO-gemiddelde.[199] Nederlandse multinationals zetten in toenemende mate R&D-activiteiten in het buitenland op, maar deze

[198] B. van Ark (2006), Recent productivity development in the European Union in comparative perspective – with a focus on the Netherlands, in: G. Evers en T. Wilthagen (red.), *Arbeidsproductiviteit en arbeidsmarktdynamiek*, OSA-publicatie, no. A217, Tilburg, blz. 25-38.

[199] De R&D-intensiteit is gedefinieerd als de R&D-uitgaven in verhouding tot het bruto binnenlands product.

gaan niet ten koste van Nederlandse R&D-activiteiten. Met andere woorden: er is geen sprake van grootschalige verplaatsing van R&D-activiteiten naar het buitenland, die de Nederlandse R&D-capaciteit in gevaar zou brengen.

Ondanks een stabiel beeld op macroniveau, is op microniveau echter sprake van een sterke dynamiek en heterogeniteit. Met het oog op de toenemende concurrentie en de versnelling van de product- en technologiecycli is de belangrijkste strategische vraag waarvoor bedrijven zich gesteld zien: *hoe de snelheid en creativiteit van R&D (en het innovatieproces) te vergroten*. De wijze waarop dit plaatsvindt verschilt sterk per sector en per onderneming, waardoor het lastig is om algemene trends te signaleren die op macroniveau gelden. Niettemin is er een aantal duidelijke indicaties die als richtinggevend kunnen worden beschouwd. Ten eerste is gecentraliseerde R&D op de thuisbasis (bijvoorbeeld Philips in Eindhoven) vooral historisch zo gegroeid. Gecentraliseerde R&D is sterk gebonden aan de omgeving waarin het opereert, vanwege schaalvoordelen, hoge 'sunk costs' van verplaatsing naar het buitenland en de verwevenheid van onderzoek met lokale toeleveranciers en kennisinstellingen. Een tweede ontwikkeling is dat de betekenis van excellente kennis steeds belangrijker wordt en ook het hebben van toegang daartoe, waar ook ter wereld deze kennis zich bevindt. Hadden buitenlandse R&D-activiteiten in het verleden vooral als taak om productie te ondersteunen, tegenwoordig wordt toegang tot excellente kennis steeds vaker aangevoerd als motief om R&D-activiteiten in het buitenland op te zetten.

De constatering uit het macrobeeld dat Nederlandse bedrijven in toenemende mate in het buitenland R&D-activiteiten ontwikkelen – die niet ten koste gaat van Nederlandse R&D – is vanuit het microperspectief bezien dus juist een positief teken. Het geeft aan dat deze bedrijven goed zijn aangesloten op de voor hen relevante internationale kennisnetwerken. Daarmee komt de in het buitenland ontwikkelde kennis via Nederlandse bedrijven weer in Nederland terecht. Maar uiteraard geldt ook het omgekeerde: in Nederland ontwikkelde kennis vindt ook zijn weg naar buiten. Dit is in toenemende mate het 'nieuwe spel' dat zich snel aan het ontwikkelen is op het gebied van internationale R&D. Om toegang tot buitenlandse excellente kennis te creëren besluiten bedrijven veelal om lokale R&D-activiteiten op te zetten, onder andere door middel van zogenoemde 'luisterposten'. Bij de ontwikkeling van dergelijke decentrale R&D-activiteiten is het thuisland nog steeds van groot belang: buitenlandse R&D-activiteiten moeten complementair zijn aan de R&D-activiteiten in het thuisland. Niettemin kunnen lokale luisterposten wel uitgroeien tot volwaardige R&D-centra met een eigen expertisegebieden. Tot slot zou het toenemende belang van excellente kennis als motief voor buitenlandse R&D-investeringen kunnen impliceren dat de relatie tussen R&D-ondernemingen en hun thuisland in betekenis afneemt. Het wordt daarmee zeker niet ondenkbaar dat investeringen in nieuwe R&D-locaties met name neer zullen slaan in een klein aantal landen met een zeer gunstig innovatie-klimaat.

Hoofdstuk 5
In hoofdstuk 4 werd beschreven dat de Nederlandse private R&D-intensiteit met ruwweg 1% sinds de jaren ’80 structureel achterloopt ten opzichte van het OESO-gemiddelde (1,5% gemiddeld). Deze structurele R&D-achterstand laat veel groeikansen onbenut, wat een belangrijke reden is voor Europese regeringsleiders om hoge R&D-ambities te formuleren (o.a. de Barcelona-doelstelling[200]). Om de structurele private R&D-achterstand te verkleinen, helpt het als duidelijk is welke factoren deze discrepantie veroorzaken. In hoofdstuk 5 wordt op kwantitatieve wijze onderzocht wat de redenen zijn voor de Nederlandse R&D-achterstand ten opzichte van het OESO-gemiddelde in 2001. Hierbij wordt gebruik gemaakt van inzichten uit de empirische literatuur.

Uit berekeningen blijkt dat de Nederlandse sectorstructuur voor meer dan 60% verantwoordelijk is voor de Nederlandse private R&D-achterstand. Dit negatieve *sectorstructuureffect* betekent dat Nederland relatief veel kennisextensieve sectoren heeft in vergelijking met het buitenland. De resterende 40% van de private R&D-achterstand wordt het *intrinsieke effect* genoemd. Dit houdt in dat Nederlandse bedrijven minder uitgeven aan R&D ten opzichte van bedrijven in vergelijkbare sectoren in andere OESO-landen. Voor een belangrijk deel wordt het Nederlandse negatieve intrinsieke effect verklaard door de Nederlandse positie in het internationaliseringsproces van bedrijfs-R&D. Er zijn indicaties dat Nederland, rekening houdend met de openheid van de economie, te weinig R&D-activiteiten uit het buitenland aantrekt. Momenteel is het aandeel dat buitenlandse bedrijven binnen onze private R&D-intensiteit hebben ruwweg 25%, maar dit zou – gezien de openheid van de Nederlandse economie – ongeveer de helft moeten zijn. Andere factoren, zoals economische instituties, het regime aan intellectuele eigendomsrechten, de overheidsfinanciering van private R&D en het aandeel snelgroeiende bedrijven leveren een zeer bescheiden bijdrage aan de intrinsieke R&D-achterstand van Nederland.

Het relatief hoge negatieve sectorstructuureffect in Nederland compliceert het terugbrengen van de totale private R&D-achterstand, omdat op korte termijn de sectorstructuur niet zomaar te veranderen is. Op basis van econometrische schattingen wordt echter aannemelijk gemaakt dat het sectorstructuureffect niet alleen maar exogeen is en op de langere termijn positief beïnvloed kan worden door verbeteringen van het intrinsieke effect, verhogingen van de publieke R&D-uitgaven en versterking van de prijsconcurrentiepositie (weergegeven door de relatieve arbeidskosten). De constatering dat de sectorstructuur ook wordt beïnvloed door andere variabelen impliceert tegelijk dat verbeteringen van het intrinsieke effect op lange termijn ook indirect de private R&D-uitgaven positief beïnvloeden via verbeteringen van het sector-structuureffect. Modelsimulaties tonen aan dat indien de R&D-intensiteit (gecorrigeerd voor de

[200] De ‘Barcelona-doelstelling’ houdt in dat de EU ernaar streeft om de R&D-uitgaven te verhogen tot gemiddeld 3% van het BBP in 2010, waarvan tweederde deel wordt gefinancierd door bedrijven. Voor zowel Nederland als de EU in haar geheel zou dit grofweg een verdubbeling inhouden van de R&D-intensiteit van bedrijven, terwijl in de EU als geheel eveneens de publieke R&D-inspanningen nog fors verhoogd zouden moeten worden.

sectorstructuur) in 2010 op het niveau van het OESO-gemiddelde zou worden gebracht, dit op lange termijn resulteert in een verbetering van het structuureffect met 27% ten opzichte van de uitgangssituatie. Eenvoudiger gezegd betekent dit dat de kennisintensiteit van de economische structuur met een kwart zal verbeteren ten opzichte van de huidige situatie. Overigens laten dezelfde modelsimulaties zien dat bij ongewijzigd beleid het negatieve effect van de Nederlandse economische structuur in de toekomst nog verder zal toenemen.

Hoofdstuk 6

Niet alleen Nederland heeft internationaal gezien een lage private R&D-intensiteit. Er is ook veel discussie over de private R&D-achterstand van Europa ten opzichte van de VS en Japan. De private R&D-intensiteit is in de EU15 0,63%-punt lager dan in de VS (in 2002). Analoog aan de methodiek gehanteerd in hoofdstuk 5 worden in hoofdstuk 6 verklaringen gezocht voor deze achterstand in private R&D. Uit de analyse blijkt dat het sectorstructuureffect een veel minder prominente rol speelt ter verklaring van de Europese R&D-achterstand ten opzichte van de VS, vergeleken met de bijdrage van het sectorstructuureffect aan de R&D-achterstand van Nederland (ten opzichte van de OESO). De R&D-achterstand van de EU15 wordt voor circa 13% verklaard door verschillen in de economische structuur met de VS. Dit betekent concreet dat het aandeel sectoren waarin relatief veel aan R&D wordt uitgegeven (lees: hightechsectoren) in de EU iets kleiner is dan in de VS. De conclusie dat de sectorstructuur een kleine rol speelt in het verklaren van de Europese R&D-achterstand verschilt met inzichten die eerder door de Europese Commissie zijn gecommuniceerd: de VS zou een kennisintensievere structuur van de economie hebben dan Europa.[201] Volgens de analyse in hoofdstuk 6 is de overige 0,54%-punt van het Europese R&D-tekort juist toe te schrijven aan andere factoren dan de structuur van de economie. De belangrijkste verklaring is de veel sterkere binnenlandse economische regulering in Europa ten opzichte van de VS. Het gaat daarbij vooral om een relatief hoge mate van productmarktregulering en relatief weinig mededinging in Europa. Twee andere belangrijke oorzaken van de R&D-achterstand van de EU zijn: een minder goed functionerend systeem van intellectuele eigendomsrechten en een lagere overheidsfinanciering van private R&D.

Hoofdstuk 7

Buitenlandse R&D-activiteiten zijn voor een kleine open economie als de Nederlandse van groot belang. Behalve een sterke directe bijdrage aan de totale R&D-intensiteit kunnen buitenlandse R&D-bedrijven ook als een transmissiekanaal voor zogenoemde kennisspillovereffecten beschouwd worden. Bovendien werd in hoofdstuk 5 aannemelijk gemaakt dat het beïnvloedbare deel van de private R&D-achterstand van Nederland voor een groot deel toe te schrijven is aan gebrekkige buitenlandse R&D-investeringen. In hoofdstuk 7 worden de belangrijkste locatiefactoren van internationale R&D-activiteiten vanuit verschillende invalshoeken geanalyseerd. Achtereenvolgens worden de resultaten behandeld van een literatuurstudie, een veldonderzoek onder buitenlandse R&D-bedrijven en een

[201] Europese Commissie (2007), *Key figures 2007 on science, technology and innovation. Towards a European knowledge area*, Brussel.

econometrische analyse op macro- en mesoniveau. Uit deze analyses blijkt dat de vijf belangrijkste locatiefactoren voor buitenlandse R&D-activiteiten zijn: de beschikbaarheid van hooggekwalificeerde arbeidskrachten, de voorraad privaat R&D-kapitaal, de toegevoegde waarde van buitenlandse bedrijven, de internationale bereikbaarheid en de kwaliteit van de kennisinfrastructuur.

De nadruk in dit hoofdstuk ligt op de econometrische analyse, omdat deze het mogelijk maakt om de effecten van locatiefactoren op buitenlandse R&D-activiteiten te kwantificeren.[202] Er zijn in het hoofdstuk twee econometrische modellen geschat. In het eerste model worden de R&D-activiteiten van buitenlandse vestigingen verklaard. Dit model is zowel op macro- als op mesoniveau geschat en leidt in beide gevallen tot grofweg dezelfde uitkomsten. In het tweede model wordt het aandeel patenten in bezit van buitenlandse bedrijven verklaard. Meer specifiek gaat het hierbij om patenten die betrekking hebben op binnenlandse uitvindingen, maar die een buitenlandse eigenaar hebben.

De resultaten van het eerste model ter verklaring van buitenlandse R&D-activiteiten laten zien dat buitenlandse bedrijven hun R&D ergens lokaliseren waar zij reeds actief zijn. Kennelijk zijn buitenlandse R&D-activiteiten (nog steeds) voor een groot deel gekoppeld aan andere activiteiten van een bedrijf, zoals productie en marketing. Uit de regressieresultaten kan worden afgeleid dat een stijging van de *toegevoegde waarde van buitenlandse bedrijven* in een land met 1% (352 miljoen US$) gepaard gaat met een stijging van de buitenlandse R&D-investeringen met 0.61% (15,7 miljoen US$). Deze uitkomst is intuïtief goed te volgen: als een bedrijf een fabriek in een gemiddeld OESO-land vestigt die voor 352 miljoen aan toegevoegde waarde genereert, dan is het aannemelijk dat hier ook een 'adaptieve' R&D-afdeling aan gekoppeld is die 16 miljoen investereert in onderzoek om productie te ondersteunen en de aanpassing van producten en technologieën aan lokale marktomstandigheden mogelijk te maken. Een tweede determinant die een significante invloed uitoefent op buitenlandse R&D-activiteiten is de *voorraad privaat R&D-kapitaal* in een land. Deze variabele is een indicator voor de opgebouwde kennisvoorraad door het bedrijfsleven. Het is interessant voor buitenlandse bedrijven om zich te vestigen in landen waar de kennisvoorraad hoog is, vanwege de potentiële spillovereffecten die hiermee gepaard gaan. Ook gaat er signaalwerking uit van de hoogte van het private R&D-kapitaal op potentiële buitenlandse investeerders, wat in het hoofdstuk getypeerd wordt als het 'place-to-be-effect'. In een land waar veel privaat R&D-kapitaal aanwezig is, zijn randvoorwaarden om onderzoek te doen kennelijk op orde en is het innovatieklimaat van bovengemiddelde kwaliteit. In kwantitatieve termen geldt dat 1% extra *private R&D-uitgaven* (132 miljoen US$) leidt tot een stijging van buitenlandse R&D-investeringen met 0.56% (14,5 miljoen US$). Het effect van *menselijk kapitaal* op de buitenlandse R&D-uitgaven is minder eenduidig. Op geaggregeerd niveau is het effect van menselijk kapitaal insignificant. Echter, op een lager aggregatieniveau wordt duidelijk dat menselijk kapitaal wel degelijk een belangrijke locatiefactor voor internationale R&D-

[202] De hierna genoemde absolute getallen bij de kwantificeringen hebben betrekking op het OESO-gemiddelde.

activiteiten is, maar alleen in sectoren die een hoge graad van technologische activiteit kennen. Hierbij gaat het vooral om de chemie en delen van de elektrotechnische industrie. Een verhoging van het aandeel hoger opgeleiden met 1%-punt leidt alleen in de chemie al tot een stijging van de private R&D-investeringen met 3,3 miljoen US$ extra.

In het tweede model ter verklaring van patenten in het bezit van buitenlandse bedrijven, blijken de hoeveelheid privaat R&D-kapitaal en menselijk kapitaal een significante invloed uit te oefenen. Het effect van menselijk kapitaal is hierbij duidelijk het sterkst. Een verhoging van het gemiddelde opleidingsniveau van de beroepsgeschikte bevolking met een half jaar leidt op lange termijn tot 10% extra buitenlandse inventies in Nederland.

Hoofdstuk 8

Hoofdstuk 8 is een overzichtshoofdstuk waarin inzichten over de internationalisering van R&D uit de voorgaande hoofdstukken gebundeld zijn. De belangrijkste conclusie uit het hoofdstuk is dat een land vooral kan leren van ‘best practices’ uit het buitenland als men zich vergelijkt met landen die een soortgelijke economische structuur hebben. Dit betekent – in het licht van de internationalisering van R&D – dat het voor een kleine open economie zoals de Nederlandse vooral leerzaam is het R&D-vestigingsklimaat te vergelijken met landen zoals Denemarken en Ierland, die ook als zodanig getypeerd kunnen worden.

Hoofdstuk 9

In het laatste hoofdstuk van het proefschrift wordt teruggegrepen op de determinanten van arbeidsproductiviteit met een sterke focus op de rol die ondernemerschap speelt. Ondernemerschap heeft tot op heden geen gevestigde plaats binnen theoretische groeimodellen en is amper behandeld in de empirische literatuur waarin productiviteitsfactoren worden onderzocht. In dit hoofdstuk proberen we deze kennislacune in de empirische literatuur te dichten.

Er worden in het hoofdstuk econometrische schattingen uitgevoerd van macromodellen die geïnspireerd zijn door vijf invloedrijke empirische studies naar productiviteitsfactoren. In deze vijf studies zijn separaat de effecten van R&D-kapitaal (privaat en publiek), technologische ‘catching-up’, arbeidsparticipatie en het aantal gewerkte uren op de ontwikkeling van de totale factorproductiviteit onderzocht. Met behulp van één dataset voor 20 OESO-landen over 33 jaar tijd (1970-2002) is getracht om de resultaten uit deze studies te reproduceren. Voorts is binnen elk van deze bestaande empirische modellen de invloed van ondernemerschap als nieuw element onderzocht. Hierbij is ondernemerschap gedefinieerd als de afwijking van de daadwerkelijke ondernemersquote ten opzichte van een evenwichtswaarde.[203] Deze evenwichts-waarde representeert de ondernemersquote gecorrigeerd voor de invloed van het welvaarts-niveau – gemeten als BBP per hoofd van de bevolking – en is econometrisch geschat in een

[203] De ondernemersquote is gedefinieerd als het aantal ondernemers in verhouding tot de beroepsbevolking.

studie van Carree e.a. (2007).[204] De definitie van ondernemerschap die we hanteren in dit hoofdstuk sluit aan bij een nieuwe stroming in de literatuur waarin ondernemerschap wordt gezien als belangrijk mechanisme om kennis te transformeren in economisch relevante kennis, wat een hogere economische groei mogelijk maakt.[205] In essentie is ondernemerschap hier dus een mechanisme om kennis te valoriseren. Dit betekent voor de interpretatie van de gebruikte ondernemersvariabele dat een *negatieve* afwijking van de ondernemersquote ten opzichte van de evenwichtswaarde een indicatie is dat het mechanisme om kennis te valoriseren onvoldoende aanwezig is in in een economie, wat een drukkende werking heeft op de productiviteit. Een *positieve* afwijking betekent juist dat kansen die zich in een economie voordoen in de vorm van kennis sneller worden benut en omgezet in een hogere productiviteit.

Uit de empirische schattingen blijkt dat ondernemerschap een significant positief effect heeft op de arbeidsproductiviteitsontwikkeling over de tijd, ongeacht de modelspecificatie. De empirische resultaten van de bestaande vijf modellen kunnen goed gereproduceerd worden. Wanneer ondernemerschap wordt toegevoegd aan de modellen, blijkt het weinig tot geen verstorende invloed te hebben op de effecten van de andere determinanten op de productiviteitsontwikkeling. De effecten van de andere variabelen blijven dus stabiel. Als ultieme empirische toets zijn alle variabelen in een allesomvattend model opgenomen ter verklaring van de ontwikkeling van de totale factorproductiviteit. De belangrijkste variabelen laten alle een significant effect zien op de productiviteitsontwikkeling en de coëfficiënten van de schattingen zijn in lijn met de geschatte coëfficiënten uit de partiële modellen.

Conclusies op metaniveau

Arbeidsproductiviteitsgroei is de doorslaggevende factor voor toekomstige economische groei. Het is bekend dat innovatie, met R&D-inspanningen als belangrijk fundament, een van de belangrijkste pijlers is voor de ontwikkeling van de arbeidsproductiviteit. In relatie tot R&D introduceert dit proefschrift drie nieuwe inzichten.

Verschillende facetten van R&D

Ten eerste laat dit proefschrift zien hoe inzichten uit de empirische literatuur kunnen worden gebruikt om verschillende effecten van R&D naast elkaar te kwantificeren. Behalve een benutting van bestaande literatuur zijn ook zelf empirische schattingen gedaan om de verschillende effecten van R&D op de arbeidsproductiviteit te onderzoeken. De resultaten bevestigen het beeld dat kleine landen vooral profiteren van buitenlandse R&D en grote landen met name van eigen R&D-inspanningen. Vernieuwend ten opzichte van bestaande weten-

[204] M.A. Carree, A.J. van Stel, A.R. Thurik en A.R.M. Wennekers (2007), The relationship between economic development and business ownership revisited, *Entrepreneurship and Regional Development*, 19(3), blz. 281-291.

[205] Z.J. Acs, D.B. Audretsch, P. Braunerhjelm en B. Carlsson (2004), *The missing link. The knowledge filter and entrepreneurship in endogenous growth*, Centre for Economic Policy Research, CEPR Discussion Paper 4783, London; D.B. Audretsch (2007), Entrepreneurship capital and economic growth, *Oxford Review of Economic Policy*, 23(1), blz. 63-78.

schappelijke inzichten is dat naast R&D-kapitaalvariabelen ook een 'catching-up'-mechanisme is opgenomen. Dit betekent dat landen die achterlopen sneller kunnen groeien door te leren van landen die technologisch geavanceerder zijn. De snelheid van convergentie naar de technologisch leider is daarbij afhankelijk van eigen onderzoeksinspanningen. Voor zover bekend is er, buiten deze studie, geen empirisch onderzoek beschikbaar waarin de R&D-kapitaalbenadering wordt gebruikt in combinatie met de technologische convergentietheorie.

Een ander nieuw inzicht is het effect van de Nederlandse sectorstructuur in relatie tot bedrijfs-R&D en vooral de endogeniteit van dit effect. Uit het onderzoek blijkt dat de kennisintensiteit van een economie geen vaststaand gegeven is en op langere termijn ook positief bijgebogen kan worden. Het feit dat de sectorstructuur in Nederland relatief kennisextensief is, betekent overigens niet dat de sectorstructuur ook een blokkade vormt voor arbeidsproductiviteitsgroei. Simpeler gezegd: Nederland heeft weliswaar een relatief klein aandeel hightechsectoren in de economie, maar is goed in staat om geld te verdienen met sectoren die technisch minder geavanceerd zijn (met name logistiek, financiële dienstverlening en groothandel). Opmerkelijk is overigens dat de R&D-achterstand van de EU15 ten opzichte van de VS voor slechts 13% verklaard wordt door verschillen in kennisintensiteit van de economische structuur tussen beide regio's. Verschillen in bedrijfs-R&D worden vooral veroorzaakt door verschillen in instituties: het stelsel van intellectuele eigendomsrechten functioneert beter in de VS en ook de lagere mate van productmarktregulering in de VS zorgt voor hogere R&D-uitgaven door bedrijven.

Ten derde worden in dit proefschrift nieuwe elementen geïntroduceerd rond het internationaliseringsproces van R&D. Zo wordt niet alleen een relatie gelegd tussen het aantrekken van R&D en de openheid van economieën, maar wordt ook langs econometrische weg onderzocht welke locatiefactoren doorslaggevend zijn voor de vestiging van internationale R&D-activiteiten. Hieruit blijkt dat R&D-kapitaal, de toegevoegde waarde van buitenlandse bedrijven (lees: productie) en de beschikbaarheid van menselijk kapitaal belangrijke factoren zijn. De factor menselijk kapitaal speelt vooral een belangrijke rol in hightechsectoren.

Ondernemerschap als bron van productiviteit

Naast R&D als belangrijke pijler voor productiviteitsontwikkeling, levert dit proefschrift empirisch bewijs dat ondernemerschap een belangrijke invloed heeft op de productiviteit van een land. Deze uitkomst is nieuw binnen de wetenschappelijke literatuur ter verklaring van de langetermijnontwikkeling van de arbeidsproductiviteit. Ondernemerschap moet hierbij geïnterpreteerd worden als een mechanisme dat kennis transformeert in economisch relevante kennis, wat vervolgens een hogere economische groei mogelijk maakt. Dit proefschrift levert daarmee empirische ondersteuning voor de notie van Joseph Schumpeter[206] dat: "*the inventor produces ideas, the entrepreneur 'gets things done'*."

[206] J.A. Schumpeter (1947), The creative response in economic history, *Journal of Economic History*, 7(2), blz. 149-159.

Curriculum Vitae

Hugo Erken werd op 4 september 1979 geboren in Ede. In 1997 haalde hij zijn VWO-diploma aan het Pallas Athene College te Ede. Datzelfde jaar begon hij zijn studie Beleidsgerichte Economie aan de Katholieke Universiteit Nijmegen, waar hij in 2001 het doctoraalexamen haalde. Zijn doctoraalscriptie "De invloed van ICT op de kwalificatiestructuur van de werkgelegenheid" is geschreven na een onderzoeksstage bij SEOR B.V., een organisatie gelieerd aan de Erasmus Universiteit Rotterdam. In juni 2002 begon Hugo voor het Ministerie van Economische Zaken in Den Haag bij de afdeling Strategie, Onderzoek en Internationale Zaken (SOI) van het Directoraat-Generaal voor Innovatie (thans DG voor Ondernemen & Innovatie). Als beleidsonderzoeker kreeg hij de kans om veel beleidsrelevant onderzoek te doen, wat deels gepubliceerd is in Nederlandstalige en Engelstalige tijdschriften en waarvan een deel terecht is gekomen in het onderliggende boek. In augustus 2006 is hij, naast zijn werk voor Economische Zaken, in deeltijd een promotietraject begonnen bij de vakgroep Centre for Advanced Small Business Economics aan de Erasmus Universiteit Rotterdam (promotor: prof. dr. Roy Thurik), dat heeft geresulteerd in dit proefschrift. Vanaf februari 2008 heeft hij binnen Economische Zaken de overstap gemaakt naar het Directoraat-Generaal voor Economische Politiek bij de afdeling Algemene Economische Politiek (AEP).

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PRODUCTIVITY, R&D AND ENTREPRENEURSHIP

How can labour productivity growth be raised in order to safeguard sustainable economic growth? This is the main question of this thesis. Labour productivity growth is the most important engine of economic growth in the OECD, and – in view of an ageing population – it will gain further importance for future prosperity. From this perspective, it is understandable that productivity is pushing the growth agenda in both academic and policymaking circles. If productivity is becoming increasingly important, then understanding differences in labour productivity patterns and its drivers becomes crucial. Predominantly, the role of two factors of labour productivity is considered in this book: research & development (R&D) and entrepreneurship. Although the importance of R&D for labour productivity development is deeply rooted in endogenous growth theory and the empirical literature, on many aspects of R&D both academics and policymakers are still in the dark. This thesis sheds light on a number of frequently asked questions: 'How important exactly is R&D for productivity growth?', 'What determines R&D expenditure within a country?', 'Does the continuing internationalisation of R&D have consequences for economic growth in countries?' and not in the least: 'How can policy contribute to fostering R&D performance?' Findings indicate that private, public and foreign R&D capital contribute as much as forty percent to labour productivity growth in the Netherlands. In addition, R&D expenditure is not exogenous and depends on a broad range of factors, such as the structure of the economy, the internationalisation process of R&D and institutional arrangements. Building on these results, the R&D shortfall of the Netherlands and the European Union is disentangled vis-à-vis the OECD and the United States, respectively. The impact of entrepreneurship on labour productivity development is even more *terra incognita* than the role of R&D. Allegedly, entrepreneurship is an important conduit to reap the benefits of knowledge creation, but there are virtually no studies that show a long-run relationship between entrepreneurship and productivity development for an international panel of OECD countries. Empirical results in this book show that entrepreneurship has a stable and significant impact on the development of productivity levels. This thesis therefore provides new evidence of the important role that entrepreneurship and R&D play for our future welfare.

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