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Total Factor Productivity and the Role of Entrepreneurship

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Total factor productivity and the role of entrepreneurship

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Abstract: Total factor productivity of twenty OECD countries for a recent period (1971-2002) is explained using six different models based on the established literature. Traditionally, entrepreneurship is not dealt with in these models. In the present paper it is shown that – when this variable is added - in all models there is a significant influence of entrepreneurship while the remaining effects mainly stay the same. Entrepreneurship is measured as the business ownership rate (number of business owners per workforce) corrected for the level of economic development (GDP per capita).

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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 relationships 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 complex relationship between entrepreneurship measures and the level of economic development (Thurik *et al.*, 2008). In this paper, we will use a new data set of business ownership data from the Compendia database (Van Stel, 2005), while business ownership will be corrected for level of economic development.[1] 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 paper is as follows. Section 2 presents the well-known theoretical framework for productivity analysis. Section 3 continues with a discussion of the determinants of productivity from an empirical perspective. Section 4 describes the model, data and variables

[1] Below we will show that this correction is necessary because both the level and the impact of business ownership rates change with the level of economic development. We will use the deviation of the actual level of business ownership from an *'equilibrium' business ownership rate* (Carree *et al.*, 2007) as our entrepreneurship variable.

used in this study. Section 5 presents the empirical results of our analyses and Section 6 concludes.

2. The framework for productivity analysis

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).[2]

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):

$$Y = TFP \cdot K^{\alpha} \cdot L_{eff}^{\beta} \qquad (1)$$

In equation (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 (1) approximates to:[3]

$$\dot{Y} = \dot{TFP} + \alpha \dot{K} + \beta \dot{L}_{eff} \qquad (2)$$

Assuming constant returns to scale ($\alpha + \beta = 1.0$), we can derive the following relationship for labour productivity growth from equation (2):

$$(\dot{Y/L}) = \dot{TFP} + \alpha\, (\dot{K/L}) + \beta\, (\dot{L_{eff}/L}) \qquad (3)$$

In equation (3), L represents input of labour measured as total hours worked. Equation (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.

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

2 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.

3 It is more accurate to formulate equation (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 (2) in terms of growth rates.

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 employment rate and the amount of hours worked. In this paper, 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:

$$(\dot{Y}/L) = \dot{TFP} + \alpha\,(\dot{K}/L) \tag{4}$$

$$\ln(Y/L) = \ln(TFP) + \alpha\,\ln(K/L) \tag{5}$$

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:

$$\Delta A = \xi\, L_A{}^{\lambda} \cdot A^{\phi} \tag{6}$$

In equation (6), 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 (11) can easily be extended, following Porter and Stern (2000):

$$\Delta A = \xi \, L_A^{\ \lambda} \cdot A^{\phi} \cdot A_{for}^{\ \psi} \tag{7}$$

As A_{for} denotes the knowledge stock abroad, equation (7) 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, 2002), 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).[4] 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).

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 catching-up, entrepreneurship, labour participation, human capital, openness to foreign trade and profitability.

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:

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[4] 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.

$$RDK = RD_t + (1-\delta)RDK_{t-1} \tag{8}$$

In equation (8) *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.[5] 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.[6] Based on these two mechanisms (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.

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

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5 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).

6 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). 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.

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.[7] 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 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 other factors as well. In order to gain an accurate measure of technological distances between countries, one should adjust productivity levels for such important other factors. In practice, however, these adjustments are difficult to conduct. Therefore, in Section 4 we will introduce an alternative catching-up variable based on patents granted by the USPTO.

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 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 (Braunerhjelm, 2008, p. 475).[8] Inspired by this limitation of endogenous growth theory, Audretsch *et al.* (2006) and Acs *et al.* (2005, 2009) develop a model that introduces a filter between knowledge in general and economically 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 economically 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

7 Coe and Helpman (1995) and Guellec and Van Pottelsberghe de la Potterie (2004) do not include a catching-up variable in their empirical models.

8 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.

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.

Acs *et al.* (2005, 2009) 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).[9] 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%.[10] 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 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

9 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.

10 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.

values of the birth and death rate on productivity are insignificant and show negative signs.[11] 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.[12] Carree and Thurik (2008) discriminate between the short- and long-run effect of new business creation on productivity growth, but they only find a significant positive effect of entrepreneurship in the short term. To recapitulate: 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. Two aspects are of importance for the present study. First, there is the negative relationship between business ownership and economic development which is well documented (Kuznets, 1971; Schultz, 1990; Yamada, 1996; Iyigyun and Owen, 1998; Wennekers *et al.*, 2009). 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).[13] Second, the role of entrepreneurship has changed since the 1990s. Studies mentioned above describe that entrepreneurship has become an important transfer mechanism to facilitate the process of knowledge spillovers. Auderstch and Thurik refer to the shift of the 'managed' to the 'entrepreneurial' economy (Audretsch and Thurik, 2001b and 2004). Taken together, these two aspects imply that with increasing economic development the importance of entrepreneurship decreased quantitatively but increased qualitatively.

Hence, in our time serial analysis we cannot simply use a measure of entrepreneurship and it becomes essential to correct the level of entrepreneurship for the level of economic development. In the present study, we use the business ownership rate as an indicator for entrepreneurship.[14] There are several ways to correct it. We choose to correct the business ownership rate for level of economic development using the setup of Carree *et al*. (2002, 2007). They introduce an *'equilibrium' business ownership rate* – which is a function of GDP per capita – in a model where deviations from this rate determine both the growth of business ownership and the pace of economic development.[15] 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. As the entrepreneurship variable in the present paper we will use the

[11] 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.

[12] 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.

[13] See also Thurik *et al*. (2008), Carree and Thurik (2003) and Wennkers *et al.* (2009) for a survey of the many mechanisms of the relationship between the business ownership rate and economic development.

[14] 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.

[15] 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). We put equilibrium between quotation marks because no theoretical equilibrium is derived. It results from an error correction mechanism.

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 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.

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 long-run elasticity found is approximately -0.5.[16] 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.

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

[16] See Annex 2 of this paper for the derivation of the long-run elasticity of hours worked per person.

development of countries. Erken and Donselaar (2006) 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 paper when discussing the impact of R&D on total factor productivity. However, we expect that openness has a separate impact on total factor productivity. 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.[17] Using a dataset for 93 countries and using nine alternative indexes of trade policy, Edwards (1998) finds empirical evidence that more open 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.

4. Model, data and variables

The following standard fixed-effects linear model is used:

$$\ln(TFP_{i,t}) = \beta_0 + \beta_1(X_{i,t}) + \beta_i DUM_i + \beta_t DUM_t + \varepsilon_{i,t} \qquad (9)$$

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

In equation (9), *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 1 these variables are made explicit, including data sources and some descriptive statistics. In Annex 4, a survey is presented of the typical specification of each model estimated in this paper.

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 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 U.S. 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.

Table 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
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

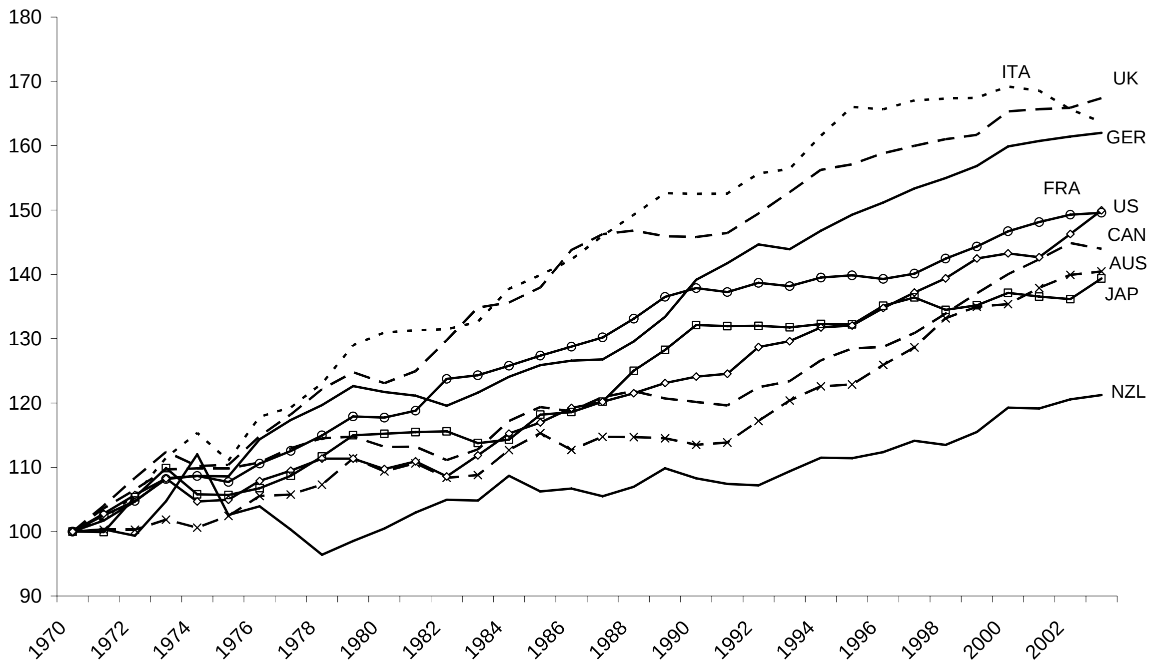
Table 1 (continued)

Variable name	Description	Source	Mean	Median	Standard Deviation	Scale
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 (%)	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	-	-	-	-	-

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.[18]

Figure 1. Development of TFP per hour worked in levels for large EU countries and non EU countries, 1970 = 100

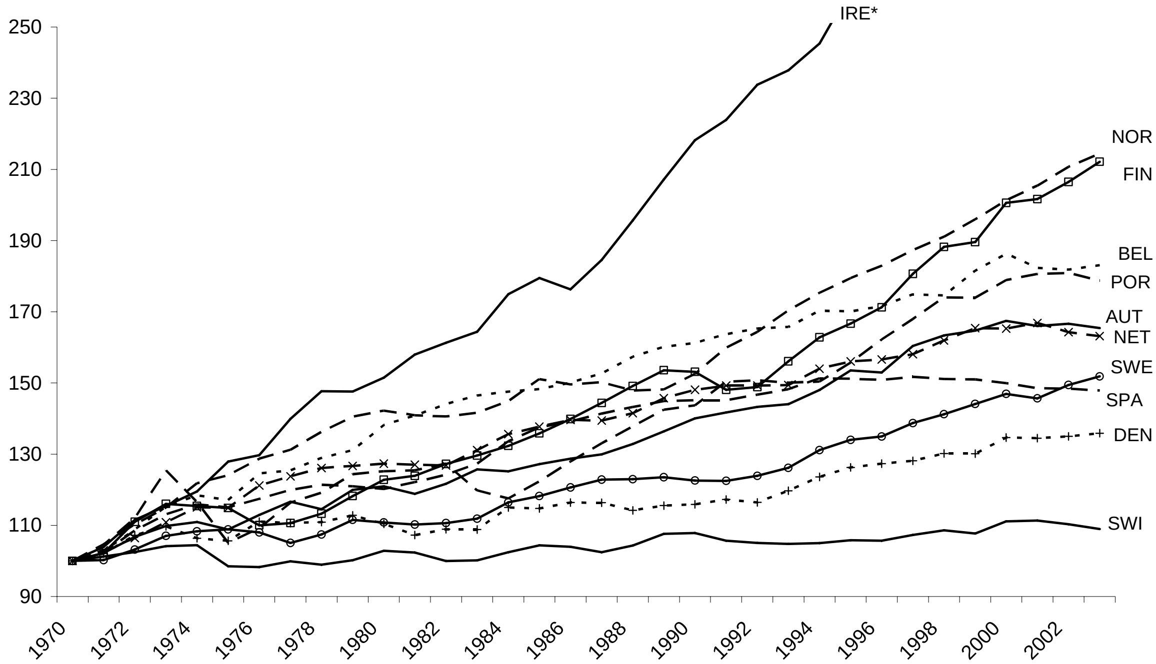


Source: own calculations based on OECD Economic Outlook database.

Abstracting from the impact of human capital and using the conventional weights for capital and labour (Section 2): $TFP = Y/(K^{1/3} \cdot L^{2/3})$. Figures 1 and 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.

[18] 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 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).

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 3, equation (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:

$$RDK_0 = RD_0 + (1-\delta)\lambda RD_0 + (1-\delta)^2 \lambda^2 RD_0 + (1-\delta)^3 \lambda^3 RD_0 + \dots \qquad (10)$$

In (10), 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

$$RDK_0 = \frac{RD_0}{1-\lambda(1-\delta)} \qquad (11)$$

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

$$g = \left(\frac{X_n}{X_0} \right)^{\frac{1}{n}} - 1 \tag{12}$$

In equation (12), 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.

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 rate* 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.

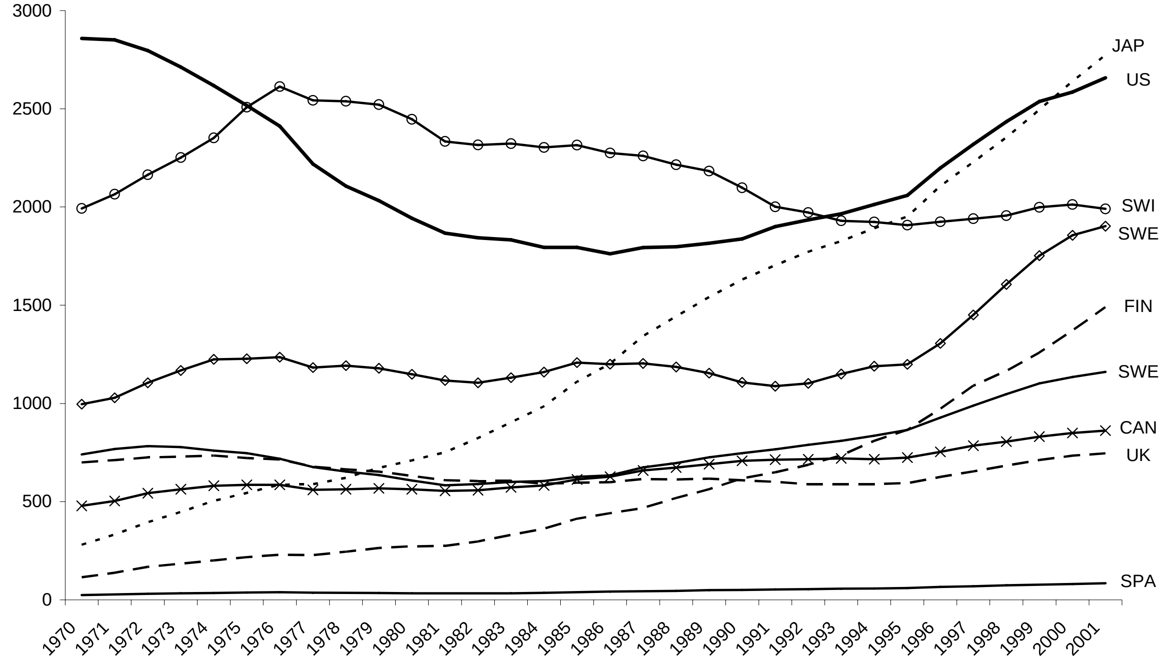
The catching-up mechanism is constructed using the cumulated knowledge stock based on data concerning the number of patents granted by the US Patent and Trade Office in relation to the labour force. The construction of the patent knowledge stock is based on Furman *et al.* (2002) and Porter and Stern (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.[19] Figure 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

[19] 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.

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).

Figure 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.

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:

$$\hat{E} = \beta - \delta \frac{Y_{cap}}{Y_{cap} + 1} \tag{13}$$

In equation (13), $\hat{E}$ 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. 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.[20] Clearly, both TFP and the ratio of the actual and the 'equilibrium' 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.

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.[21] 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.

[20] 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 a business ownership rate above the 'equilibrium' business ownership rate is not detrimental for economic growth. An equivalent asymmetry will be tested for in the present paper.

[21] 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.

5. Empirical results

We adopt a two-step cointegration approach which will be explained in Section 5.1. Section 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 variable. Subsequently, we combine the models into one comprehensive ‘all in the family’ model. In Section 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 5.4 we interpret some of the estimation results.

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 2 shows the ADF test of our dependent TFP variable.

The t-values in Table 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 2. ADF test on dependent variable (total factor productivity)

	$\Delta \ln(TFP)$
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 5.3 – and note that all estimated long-run equilibrium models in Section 5.2 have a cointegration vector. In addition, the estimations show a very low the Durbin-Watson statistic in each model (Section 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.

5.2 Step 1: estimating long-run cointegration relationships

Table 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 4 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).[22] As a consequence, the functional form of the reproduced models in this paper 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.

[22] The 'Belorgey' model is the only exception which is estimated using so-called generalized method of moments (GMM), a dynamic panel technique.

Table 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 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 4 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 both equations (8) and (9) 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 equation is estimated using GMM methodology, where we use the lagged levels of *TFP* ($TFP_{i,t\text{-}2}$ and $TFP_{i,t\text{-}3}$) as instruments for the delta lagged dependent variable $\Delta TFP_{i,t\text{-}1}$ (see Greene, 2000, pp. 583-584). We use an alternative business cycle variable compared to Belorgey *et al.* (see Section 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 4 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 ($1\text{-}c_\lambda$) 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 4 for the exact specification of column (13).

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.[23] 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.

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 3 human

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23 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.

capital is incorporated in the 'Coe and Helpman' specification.[24] 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 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 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).[25] The estimated coefficient for human capital is largely in accordance with the empirical results found by Bassanini and Scarpetta (2001, 2002).

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 4, our catching-up variables are constructed using a different 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 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 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.[26] 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'

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24 Conform Engelbrecht (1997, p. 1481), we lag our human capital variable by one year; see Annex 4 for the exact specification.

25 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.

26 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).

equations, adding entrepreneurship does not affect the other outcomes (although the effect of the human capital variable declines, see footnote 25) 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 3 we show the initial estimates of the 'Guellec and Van Pottelsberghe' specification (equation (A.20) in Annex 4). The impact of domestic public R&D capital on the 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 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 3. It is beyond the scope of this paper 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_λ is fixed at 0.56. This implies that public R&D is given a weight of 0.44 (1- c_λ).

Column (8) of Table 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 4, equation (A.21). 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% × 0.15) and public R&D is given a coefficient of 0.07 (44% × 0.15). Column (9) of Table 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).[27]

Both participation variables show a significant negative effect on the development of TFP levels.[28] 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 *et al.* (2006) the participation variable (employment share) shows a higher negative coefficient (-0.50) compared to the variable hours worked (-0.37).[29] 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 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}).[30] 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 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 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

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27 For some literature on GMM methodology, see Hall (2005), Blundell and Bond (2000), Greene (2000, p. 582 ff).

28 Using different GMM specifications does not seriously alter the estimation results. These empirical sensitivity analyses are available on request with the authors.

29 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.

30 Equation (A.26) in Annex 4 shows the specific model.

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 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.26) in Annex 4 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).[31] 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, as reflected by the much higher R^2 (0.95 as opposed to 0.84 in column (7) in Table 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.[32] 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.26) in Annex 4). 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 0.45, which is derived in Section 2.1 of this paper 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).

[31] The elasticity is slightly lower than 0.15, because the exact estimated coefficient is 0.245.

[32] As was the case in the equations presented in columns (8) and (9) in Table 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).

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 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.

5.3 Step 2: short-term dynamics and cointegration tests

To study the short-term dynamics of the long-run relationships in section 5.2 and simultaneously test for cointegration, we use the following error correction model:[33]

$$\Delta \ln(TFP_t) = \alpha\Delta \ln(TFP_{t-1}) + \beta\Delta \ln(TFP^*) + \varphi\left[\ln(TFP_{t-1}) - \ln(TFP_{t-1}^{\ \ *})\right] \qquad (14)$$

Equation (14) 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 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 (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 coefficient α) to take into account a *gradual* adjustment of the estimated long-run values towards the actual TFP values.[34]

Table 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 3).

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[33] 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.

[34] 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 (19)): the higher the coefficient (the closer to 1), the longer the transformation process will take.

Table 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.

Table 5. Error correction models estimation

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***
A	$\Delta\ln(TFP_{t-1})$	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 between 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.

In Table 5, the error correction model is used to study the robustness of the other long-run equilibrium models from Table 3. Table 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 is high (β), ranging from 64% to 88%. A difference with the estimations in Table 4 is that the lagged dependent variable (α) has a significant role in the error correction models presented in Table 5.

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 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 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 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 1) in combination with estimation results of column (13) from Table 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.[35] 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 3 (coefficient c_{10}) to the annual mutation of the interacted catching-up variable (CU^{RD} in Table 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 7.

[35] See Section 4 for more information on how this variable is constructed.

Table 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 1) and the estimated coefficient of the interacted catching-up variable (c_{10}) in Table 3 (column (13)).

Table 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 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, for the calculations in Table 3 we replace our entrepreneurship variable being the deviation from 'equilibrium' business ownership rate, $\log(e/\hat{E})$, by the straightforward business ownership rate, $\log(e)$. It appears that in the seven cases where entrepreneurship is part of the regression its coefficient is always positive while its t-value is in excess of 1.3 in five cases and in excess of 2.5 in two cases. Hence, the impact of entrepreneurship on total factor productivity does not hinge entirely around its correction for level of economic development but, as expected, its significance increases if our entrepreneurship variable is appropriately corrected for the level of economic development. 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.[36] 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.

Table 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

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 8 shows the results.

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.

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

[36] 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’).

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. We argue that this correction is necessary since the importance of entrepreneurship increases with increasing levels of economic development while its own level decreases. 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.

A number of future research options are important to address. First, it is worthwhile to examine 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. Secondly, 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 *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 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 $\gamma > 0$, where *TFP* is total factor productivity, $BOR^* = e/\hat{E}$, e is the business ownership rate, $\hat{E}$ 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 $\frac{d\ln(TFP)}{d\ln(e/\hat{E})}$ 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 ($\hat{E}$) 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 ($\hat{E}$) and an estimated error term (μ):

$$e = \hat{E} + \mu \tag{A.3}$$

Moreover, we know that in (A.1) $\alpha > 0$ ($\approx 1/3$) and in (A.2) $\beta > 0$ (≈ 1.18) and $\delta > 0$ (≈ 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 δ >0.

Using (A.1) we can write

$$\frac{dTFP}{d\left(e/\hat{E}\right)} = \frac{dTFP}{dy} \cdot \frac{dy}{d\left(e/\hat{E}\right)} = \frac{1}{k^{\alpha}} \left(\frac{d\left(e/\hat{E}\right)}{dy} \right)^{-1} \quad \begin{smallmatrix} < \\ > \end{smallmatrix} \quad 0 \iff \mu \begin{smallmatrix} < \\ > \end{smallmatrix} 0 \tag{A.6}$$

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. Openness 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:

$$\ln(TRADE_{i,t}) = 3.02 - 0.23 \ln\left(\frac{GDP^h}{GDP^f}\right)_{i,t} + 0.02\, TREND \qquad \text{(A.12)}$$

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:

$$\ln(OPENECO_{i,t}) = \ln(TRADE_{i,t}) + 0.23 \ln\left(\frac{GDP^h}{GDP^f}\right)_{i,t} \qquad \text{(A.13)}$$

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. Technical aspects of estimated models

In this annex an overview is presented of the equations in Section 5.2, Table 3. The symbols in the equations are presented in detail in Table 1 in Section 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 3.

Coe and Helpman
The 'Coe and Helpman' equation presented in column (1) of Table 3 is specified as follows:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\, RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \quad \text{(A.14)}$$

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 3), being an index measuring the deviation from the 'equilibrium' business ownership rate (*BOR**), (A.15) becomes:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\, RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + c_8 \ln(BOR^*_{i,t}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \quad \text{(A.15)}$$

Engelbrecht
In the 'Engelbrecht' model (column (3) in Table 3), human capital (*HC*) as a determinant of productivity is taken into consideration. The model is estimated by means of the following equation:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\, RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + c_7 \ln(HC_{i,t-1}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \quad \text{(A.16)}$$

Incorporation of entrepreneurship in the model (see column (4) in Table 3), (A.17) leads to:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t}) + c_5\, RDS_{i,t}/100 \times \ln(BRD^h_{i,t}) \\ &+ c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t}) + c_7 \ln(HC_{i,t-1}) + c_8 (BOR^*_{i,t}) + \sum_i f_i DUM_i + \varepsilon_{i,t}\end{aligned} \quad \text{(A.17)}$$

Griffith, Redding and Van Reenen
The general 'Griffith' equation that is estimated in column (5) of Table 3 is:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_7 \ln(HC_{i,t-2}) + c_9\, CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + \sum_i f_i DUM_i + \varepsilon_{i,t} \qquad \text{(A.18)}$$

CU captures the catching-up mechanism as discussed in Section 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 3), (A.19) can be rewritten to:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_7 \ln(HC_{i,t-2}) + c_8 \ln(BOR^*_{i,t}) + c_9\, CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + \sum_i f_i DUM_i + \varepsilon_{i,t} \qquad \text{(A.19)}$$

Guellec and Van Pottelsberghe de la Potterie
Column (7) of Table 3 is estimated using the following equation based on Guellec and Van Pottelsberghe de la Potterie:

$$\ln(TFP_{i,t}) = c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_3 \ln(PRD^h_{i,t-2}) + c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t-1}) + c_{13} \Delta UR_{i,t} + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t} \qquad \text{(A.20)}$$

The control variable ΔUR represents the first difference in the unemployment rate, which is intended 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 3) is as follows:

$$\ln(TFP_{i,t}) = c_1 + c_4 \times \left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ln(PRD^h_{i,t-2})\right] + c_6\, imsh_{i,t-1} \times \left[c_\lambda \ln(BRD^f_{i,t-1}) + (1-c_\lambda)\ln(PRD^f_{i,t-2})\right] + c_{13}\Delta UR_{i,t} + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t} \qquad \text{(A.21)}$$

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 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:

$$\ln(TFP_{i,t}) = c_1 + c_4 \times \left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ln(PRD^h_{i,t-2})\right] + c_6\, imsh_{i,t-1} \times \left[c_\lambda \ln(BRD^f_{i,t-1}) + (1-c_\lambda)\ln(PRD^f_{i,t-2})\right] + c_7 \ln(BOR^*_{i,t}) + c_{13}\Delta UR_{i,t} + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t} \qquad \text{(A.22)}$$

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 3):

$$\begin{aligned}\Delta \ln(TFP_{i,t}) &= c_1 + c_{11}\Delta LPAR_{i,t} + c_{12}\Delta HRS_{i,t} + c_{15}\Delta \ln(BUSCYCLE_{i,t}) \\ &+ c_{19}\Delta \ln(TFP_{i,t-1}) + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \tag{A.23}$$

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. $TFP_{t\text{-}1}$ 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:

$$\begin{aligned}\Delta \ln(TFP_{i,t}) &= c_1 + c_7\Delta \ln(BOR^*_{i,t}) + c_{11}\Delta LPAR + c_{12}\Delta HRS \\ &+ c_{15}\Delta \ln(BUSCYCLE_{i,t}) + c_{19}\Delta \ln(TFP_{i,t-1}) + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \tag{A.24}$$

As we estimate equation (A.24 and A.25) using GMM methodology, we use the lagged levels $\ln(TFP_{i,t-2})$ and $\ln(TFP_{i,t\text{-}3})$ 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:

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_2 \ln(BRD^h_{i,t-1}) + c_5\, RDS_{i,t-1}/100 \times \ln(BRD^h_{i,t-1}) + c_6\, imsh_{i,t-1} \times \ln(BRD^f_{i,t-1}) \\ &+ c_7 \ln(HC_{i,t-1}) + c_8 \ln(BOR^*_{i,t}) + c_9 CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + c_{11} \ln(LPAR_{i,t}) + c_{12} \ln(HRS_{i,t}) \\ &+ c_{13}\Delta UR_{i,t} + c_{14} \times \ln\left(SECCOM_{i,t-1}/RDI_{i,t-1}\right) + c_{15} \ln(BUSCYCLE_{i,t}) + c_{16} \ln(CIS_{i,t-1}) \\ &+ c_{17} \ln(TR_{i,t}) + c_{18} \ln(OPENECO_{i,t}) + c_{20} \times DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \tag{A.25}$$

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 4 of this paper and in Annex 3. The final model with public and private R&D separated (final column (13) in Table 3) is somewhat more complex than equation (A.26):

$$\begin{aligned}\ln(TFP_{i,t}) &= c_1 + c_4\left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ln(PRD^h_{i,t-2})\right] + c_5\, RDS_{i,t-1}/100 \\ &\times\left[c_\lambda \ln(BRD^h_{i,t-1}) + (1-c_\lambda)\ln(PRD^h_{i,t-2})\right] + c_6\, imsh_{i,t-1} \times \left[c_\lambda \ln(BRD^f_{i,t-1}) + (1-c_\lambda)\ln(PRD^f_{i,t-2})\right] \\ &+ c_7 \ln(HC_{i,t-1}) + c_8 \ln(BOR^*_{i,t}) + c_9 CU_{i,t-1} + c_{10}\, CU^{RD}_{i,t-1} + c_{11} \ln(LPAR_{i,t}) + c_{12} \ln(HRS_{i,t}) \\ &+ c_{13}\,\Delta UR_{i,t} + c_{14} \times \ln\left(SECCOM_{i,t-1}/RDI_{i,t-1}\right) + c_{15} \ln(BUSCYCLE_{i,t}) + c_{16} \ln(CIS_{i,t-1}) \\ &+ c_{17} \ln(TR_{i,t}) + c_{18} \ln(OPENECO_{i,t}) + c_{20}\, DUM^{91}_{GER} + \sum_i f_i DUM_i + \sum_t f_t DUM_t + \varepsilon_{i,t}\end{aligned} \tag{A.26}$$

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 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).