

Economic Development and Technology Diffusion*

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Abstract

I first present a New Economic Geography model and analyze the impact of R&D on economic development of integrating countries. I find that technology diffusion and skilled labor migration stimulates economic development through fix cost reduction on a firm level. As the inclusion of foreign technology matters for structurally backward countries, I second use time series data for Greece, Portugal, Spain and Ireland representing European integration during the 1980s and 1990s. In considering three different technology diffusion channels, estimates, however, reduces to Portugal as test procedures confirm nonstationarity and cointegration only for this country. I find empirical evidence for bilateral trade as a diffusion channel but not for FDI or foreign patents.

JEL Classification: C22, C68, O30, R12

Keywords: Economic Geography, Agglomeration, Technology Diffusion, Nonstationary Time Series

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1 Introduction

As widely acknowledged, European integration led to an economically catching-up process of Greece, Portugal, Spain and Ireland in the 1980s and 1990s. As European countries grow together, acceding countries push their economies by attracting labor-intensive production and mobile factors – in some cases (sectors) at the core members' expense. However, economic integration is not the only source of potential growth and economic prosperity for structurally backward countries. Following Keller (2004), the transfer of foreign technology and its inclusion in domestic production are widely believed to promote and strengthen economic development as well. Bilateral trade, for example, is considered to transfer technology between trading partners. Moreover, multinational firms diffuse technological knowledge through their affiliates abroad. And finally, as proposed by Eaton and Kortum (1999), the pattern of international patenting indicate of where ideas are going and therefore reflect the link between the source and the destination of transferred technology. Hence, since relationships between countries are getting closer within economically integrating regions, integration and technology diffusion lead to self-reinforcing processes spurring and fostering economic development – especially for structurally backward countries.

To deal with, I first present a New Economic Geography (NEG) model and analyze the impact of R&D activity and technology diffusion on economic development of integrating countries. To my knowledge, there is no theoretical work within the NEG-models dealing with both, economic integration as well as technology diffusion. As technology matters for structurally backward countries, I second estimate the impact of domestic and foreign R&D expenditure on labor productivity for Greece, Portugal, Spain and Ireland – representing European integration. Accounting for nonstationarity and cointegration, I use the Error Correction (EC) model as to quantify properly the long-run relationship between labor productivity and R&D expenditure and to determine foreign technology diffusion. Hence, I revert to the data used by Hafner (2007) and analyze three different technology diffusion channels: patent applications, bilateral trade and FDI. Again, as far as I see, there is no empirical work doing so.

The structure of this paper is described as follows. The next section discusses briefly economic integration and technology diffusion. Section 3 presents a two-country model with R&D activity in a NEG-framework. The results of numerical simulations of economic integration and technology diffusion are presented in section 4. Section 5 states the regression

equation to quantify technology diffusion and discusses the data and nonstationary issues. The results of the testing procedures and empirical estimations are in section 6. Section 7 concludes. Specific details on parameter choice and numerical simulation as well as further information about the data are in appendix (A) and (B) respectively.

2 European Integration and Technology Diffusion

In May 2004, Central and Eastern European countries joined the European Union (EU) and augmented the EU to 25 countries marked as the biggest enlargement in European history. Decades before, different waves of integration steadily increased the number from originally six core countries, which agreed to form a common European market in 1957, to 15 member countries by the end of the last century. Amongst the first countries to join the post-formed European Community were Greece, Portugal, Spain and Ireland, which experienced a remarkable economic development since then. To deal with, Hafner (2006) provided some stylized facts on macroeconomic indicators of European integration by grouping Germany, France, Italy and the Benelux countries as the EU-Core and Greece, Portugal, Spain and Ireland as the EU-Periphery. By looking on GDP per capita for 1981-2001 as well as on skilled and unskilled net-earnings per hour for 1982-2003,¹ the author showed that the income gap between core and periphery countries narrowed remarkable in the last years. Turning to disaggregated data instead, GDP per capita for Ireland, for example, exceeded those from Germany and France since 1998. This is a remarkable finding, because in 1981 Ireland had the second lowest GDP per capita rate amongst the acceding countries only slightly ahead of Portugal.² According to the Industrial Development Agency (IDA) as an Irish government institution, over 1.050 oversee companies have chosen Ireland as their main European base. These multinationals are operating in high tech industry sectors such as e-business, engineering, communication and medical technologies and financial services creating sufficient technological spillovers to push the country as a whole. Since GNI per capita for Ireland has been growing as well – closing the GNI per capita gap to European core countries³ – there is no

¹ The Data used is from the *Economic Outlook* Database by the OECD and from the *Price and Earning Statistics* by the UBS.

² According to figures from the *Economic Outlook* Database by the OECD, GDP per capita in current US\$ (PPP) in 1998 was 23.935 for Ireland, 23.288 for Germany and 23.424 for France. Amongst the acceding countries, GDP per capita in current US\$ (PPP) in 1981 was for Spain 7.308, for Portugal 5.845, for Greece 7.755 and for Ireland 6.921.

³ According to World Bank figures, the gap between Germany and Ireland in current US\$ (PPP), for example, was 4.360 in 1996 and 744 in 2002

doubt that Ireland has gained from both, European integration and technology diffusion. Hence, economic integration and the inclusion of foreign technology seems to benefit acceding countries – even (or particularly) those with a lower development status – and promote economic prosperity. A hope that actually share all of the Central and Eastern European countries while acceding and integrating to the EU.

Before turning to the model, I figure out some key features of the NEG-framework and discuss briefly technological spillover effects as to introduce the main theoretical concepts of the paper.

NEG-Models and Technological Spillover Effects

Following Hirschmann (1958) cost and demand linkages arise as firms are able to use intermediate goods more cheaply and face a greater consumer demand, where other firms and consumers are concentrated. This leads to circular causality and to self-reinforcing agglomeration effects of industrial activity (*pull forces*). At the same time competition in product and factor markets increases with the number of locally concentrated firms. These neoclassical forces as well as trade and transportation costs work against industrial agglomeration (*push forces*). Hence, the trade off between these two forces determines the pattern of industrialization and the distribution of mobile factors between countries. As a key feature of NEG-models, spatial concentration of industry occurs when trade (transport) costs are at an intermediate level, whereas at high and at low trade (transport) costs industrial activity is more likely to be equally distributed.

To cope with, I use an agglomeration model with Marshallian externalities⁴ and add international migration of skilled labor. Hence, I assume skilled labor as a single input factor employed in a public R&D sector. I further assume that firm' fix costs are reduced by the use of public financed research results, which itself depends on the presence of skilled labor. This idea is derived from Ottaviano (2001) and Forslid (1999), where a “footloose entrepreneur” is required as a fixed input to produce one single variety of industrial goods. Hence, the location of industry in these papers is driven by migration owing to real wage differences. Here, immigration of skilled labor leads to higher domestic R&D and therefore to lower break-even points for firms and to higher market entry. Hence, as in Forslid (1999), the presence of skilled labor determines the number of firms and industrial goods. Studies such as from

⁴ For Marshall (1890) “mass production, the availability of specialized input services and the formation of highly skilled labor as well as the production of new ideas are crucial for the formation of industrial clusters”; see Fujita and Thisse (2002).

Feldman and Florida (1994) emphasize the link of skilled labor, R&D activity and the clustering of firms. Accordingly, innovation is more likely to cluster in regions/countries where R&D-oriented firms and universities are established. As such regions become more attractive further concentration of firms and mobile factors occurs, pushing a region's capacity to innovate and grow. Moreover, the impact of research and its effect on agglomerations also depends on the type of technological spillover. Following Martin and Ottaviano (1997), there is a distinction between *local* and *global* spillover effects of R&D implementation. On the one hand, the availability and applicability of research may be restricted locally: blueprints cannot be transferred and applied to other countries owing to their specific use or property rights. But on the other hand, the use of technology-embedded intermediate goods, the interchange of human capital and ideas encouraged by multinational firms as well as foreign patent applications raise the degree of technological spillovers and therefore the likelihood of economic prosperity for developing countries. Accordingly, a crucial role has to be credited to technological spillover effects and its impact on economic development of integrating countries.

3 A Static Equilibrium Model

The model relies on the concept of monopolistic competition from Spence (1976) and Dixit and Stiglitz (1977), and its adaptation to regional economics by Krugman (1991a, 1991b) and Krugman and Venables (1995). Additionally, vertical linkages among firms like in Venables (1996), Fujita, Krugman und Venables (1999) and Fujita and Thisse (2002) are assumed. In order to deal with economic integration, iceberg trade costs as proposed by Samuelson (1954) are introduced.

3.1 Assumptions

There are two countries ($i = 1,2$), with identical endowments of mobile and immobile factors of production (unskilled workers (L_i), skilled labor (H_i), land (B_i), and industrial products as intermediate goods, ($Z_{M,i}$)). Unskilled labor is mobile between sectors within a country and skilled labor between countries. The share of land is assumed to be fixed. Intermediate goods are subject to trade costs. Both countries have the same technology and there are three sectors (agriculture (A), manufacturing (M) and public R&D (S)). Public research results are assumed to reduce fix costs at the firm level.

Agricultural Sector

Agriculture is a Walrasian sector with perfect competition and constant returns. The homogenous agricultural good ($Q_{A,i}$) is traded without trade costs. Production is supposed to follow a Cobb–Douglas functional term using B_i and unqualified labor ($L_{A,i}$). Unskilled labor can be employed by the agricultural sector as well as by the manufacturing sector. The nominal wage rate paid in the agricultural sector with respect to unskilled labor is:

$$w_{A,i} = \theta(L_i - L_{M,i})^{\theta-1} B^{1-\theta}, \quad \theta \in (0,1), \quad (1)$$

with $L_{M,i}$ as unqualified labor employed in the manufacturing sector, θ as the partial production elasticity of unqualified labor and $B_i = B$.

Following Puga (1999), I use a restricted profit condition to express agricultural gains ($\pi_{A,i}$) as a function of the price of the agricultural good ($p_{A,i}$), nominal wages and land:

$$\pi_{A,i}(p_{A,i}, w_{A,i}, B) = \max \left\{ p_{A,i} Q_{A,i} - w_{A,i} L_{A,i} \mid Q_{A,i} \leq f(L_{A,i}, B) \right\}. \quad (2)$$

Due to the assumption of constant returns, $\pi_{A,i}$ in equation (2) is homogenous of degree one in B and can be rewritten by $p_{A,i} = 1$ to:

$$\pi_{A,i}(1, w_{A,i}, B) = B r_i(w_{A,i}), \quad (3)$$

with $r_i(w_{A,i})$ as maximized profit per unit land in country i .

Manufacturing Sector

I assume monopolistic competition and increasing returns for the manufacturing sector. In addition to unskilled labor, the manufacturing sector uses an aggregate ($Z_{M,i}$) of industrial products h as intermediate goods. Aggregate supply ($Q_{M,i}$) follows a Cobb–Douglas functional term with a CES aggregate of intermediate goods:

$$Q_{M,i} = L_{M,i}^{1-\mu} Z_{M,i}^{\mu}, \quad Z_{M,i} = \left(\sum_{j=1}^2 \int_{h \in N_j} x_{ji}^{\rho}(h) dh \right)^{1/\rho}, \quad \mu \in (0,1); \quad \rho \in (0,1), \quad (4)$$

with ρ as the degree of product differentiation, N_i as the number of firms (= number of goods) in country i and μ as the partial production elasticity of intermediate goods. The quantity of the produced good j in country i is denoted by x_{ji} . The cost function ($C_{M,i}$) of a single manufacturing firm in country i is:

$$C_{M,i}(k) = (\alpha_i + \beta x_i(k)) w_{M,i}^{1-\mu} q_i^\mu, \quad (5)$$

where q_i is the price index and $w_{M,i}$ is the nominal wage rate paid in the manufacturing sector. Perfect mobility of unskilled workers across sectors ensures that the wage is identical in the manufacturing and agricultural sector ($w_{M,i} = w_{A,i}$). As usual, production costs of a single variety of firm k in country i are divided into a fixed and variable part, α_i and β respectively. Variable costs do not differ between countries. Due to the assumption of increasing returns, $x_i(k)$ also represents the produced amount of good k in country i .

Firms are price setters and are therefore able to raise prices ($p_{M,i}$) above marginal costs:

$$p_{M,i}(k) = (1/\rho) \beta w_{M,i}^{1-\mu} q_i^\mu, \quad (6)$$

with $(1/\rho)$ as a constant mark-up factor. The short-term profits ($\pi_{M,i}$) of a firm, determined by free entry into markets, are calculated as:

$$\pi_{M,i}(k) = \frac{P_{M,i}}{\sigma} (x_i - x_i^b), \quad \sigma \in (1, \infty), \quad (7)$$

with $\sigma = 1/(1-\rho) > 1$ as the elasticity of substitution between goods and $x_i^b = \alpha_i(\sigma-1)/\beta$ as break-even output. In the long-run, firm profits in equation (7) are zero.

Public R&D Sector

The public R&D sector uses skilled labor as input factor. Under the assumption of decreasing returns, perfect competition and a Cobb Douglas functional term, research output (S_i) in country i can be written as:

$$S_i = H_i^\iota, \quad \iota \in]0,1[, \quad (8)$$

with ι as the partial production elasticity of H_i . Technological knowledge (A_i) in country i is determined by the compounded output of the R&D sectors. Depending on technology diffusion and therefore on the availability of research results from abroad, technological knowledge is:

$$A_i = (S_i + \Gamma S_j), \quad j = 1, 2; j \neq i; \Gamma \in (0, 1), \quad (9)$$

with Γ as the degree of technological spillover effect.⁵ A global spillover effect ($\Gamma = 1$) means that both countries transfer research results to each other without losing application or, to put it differently, without redundancy. By $\Gamma = 0$, a country's research level is determined by its own research activity. As discussed, technological knowledge reduces fix costs at the firm level:

$$\alpha_i = \kappa / A_i, \quad \kappa > 0 \quad (10)$$

where κ is a constant parameter. Hence, a higher A_i leads to lower fix costs and by x_i^b in equation (7) to higher short run profits and therefore to higher market entry.

Government Taxation

The public R&D sector and therefore skilled labor is financed by a lump sum tax (t_i) on national income (Y_i):

$$w_{H,i} H_i = t_i Y_i, \quad (11)$$

with $w_{H,i}$ as the nominal wage rate for skilled labor in country i . For simplicity, input factors are paid by their marginal product derived from equation (8):⁶

$$w_{H,i} H_i = \iota H_i^{\iota} = t_i Y_i. \quad (11.1)$$

⁵ Owing to calibration reasons for numerical simulation, I relate domestic and foreign R&D to total R&D, $(S_i + \Gamma S_j)/(S_i + S_j)$ for $j = 1, 2$ and $j \neq i$, and therefore normalize technological knowledge to $A_i \in (0, 1)$. The interpretation does not change: the higher the domestic (foreign) R&D activity, the higher the domestic (foreign) technological knowledge and vice versa.

⁶ See Anderson and Forslid (2003), Baldwin and Krugman (2004) as well as Hafner (2006) for taxation of mobile factors in the presence of agglomeration forces and diminishing (transportation) trade costs.

Hence, equation (11.1) states that there is an income transfer towards factors employed in the R&D sector. Y_i is traced back to factor income of unskilled and skilled labor as well as to gains resulting from agriculture and manufacturing:

$$Y_i = w_{A,i}L_i + w_{H,i}H_i + Br_i(w_{A,i}) + \int_{k \in N_i} \pi_{M,i}(k)dk . \quad (12)$$

Substituting equation (11) in equation (12) and rearrangement yields to:

$$(1-t_i)Y_i = w_{A,i}L_i + Br_i(w_{A,i}) + \int_{k \in N_i} \pi_i(k)dk \equiv Y_i^{GDP} , \quad (13)$$

with Y_i^{GDP} as GDP. Note that Y_i^{GDP} consists only of factor income of unqualified labor, agricultural gains and short run profits: within a country, an income tax and its redistribution as factor payments do not change total factor income. To keep analysis simple, tariff does not generate domestic income and therefore is not considered by equation (13).

Consumption

A representative consumer (R) has time-invariant, identical preferences towards goods produced in either country. Love of variety preferences is a Cobb–Douglas CES nest using the agricultural good and an aggregate of industrial goods. Using for consumption the same CES aggregate as for production, the utility function (U_i^R) for a representative consumer is:

$$U_i^R = Q_{A,i}^{1-\gamma} Z_{M,i}^\gamma , \quad Z_{M,i} = \left(\sum_{j=1}^2 \int_{h \in N_j} x_{ji}^\rho(h)dh \right)^{1/\rho} , \quad \gamma \in (0,1), \quad (14)$$

with γ as the consumption share of industrial products. Optimization leads to the following indirect utility function:

$$U_i^R = [Y_i^R (1-t_i)]^{-(1-\gamma)} q_i^{-\gamma} . \quad (15)$$

For analytical reasons, the price index for industrial products is the same for consumers and producers.

Migration-Decision of Skilled Labor

Skilled labor takes into account local tax rates, the price level and nominal wage rates. Hence, the migration condition of skilled labor is derived from equation (15) to:

$$\frac{q_i^{-\gamma}(1-t_i)(w_{H,i})}{q_j^{-\gamma}(1-t_j)(w_{H,j})} = 1, \quad j = 1,2; j \neq i. \quad (16)$$

3.2 General Equilibrium Conditions

Owing to the assumption of increasing returns, each good is produced by a single firm k located in a single region. Hence, total demand for one good produced in country i is composed of consumer and producer demand from both countries:

$$x_i(k) = p_{M,i}(k)^{-\sigma} \left(e_i q_i^{(\sigma-1)} + e_j q_j^{(\sigma-1)} \tau_{ji}^{(1-\sigma)} \right), \quad j = 1,2; j \neq i; \tau_{ji} \geq 1. \quad (17)$$

Intermediate goods are subject to iceberg trade costs (τ_{ji}): traded units greater than one in country i shrink to one unit in country j . Hence, parts of traded quantity melt away. $p_{M,i}(k)$ is the producer price and is listed as the *free-on-board* price (*FOB*).

The price index for the bundle of industrial goods in country i can be written as:

$$q_i = \left[\int_{h \in N_i} (p_{M,i}(h))^{(1-\sigma)} dh + \int_{h \in N_j} (p_{M,ji}(h) \tau_{ji})^{(1-\sigma)} dh \right]^{1/(1-\sigma)}, \quad j = 1,2; j \neq i. \quad (18)$$

In each country, the price index depends on local prices, which in turn depend on *FOB* prices and local trade costs.

Total expenditure (e_i) is composed of consumer and producer expenditure on industrial products and can be specified for country i as:

$$e_i = \gamma \left(w_{A,i} L_i + B r_i(w_{A,i}) + \int_{k \in N_i} \pi_{M,i}(k) dk \right) + \mu \int_{k \in N_i} C_i^P(k) dk. \quad (19)$$

Due to the assumption of lump-sum taxation and its redistribution, factor income from the R&D sector does not enter to equation (19). The first part of equation (19) stands for the net

expenditure of consumers, while the second part describes the share of firms' cost spending. The remaining part of cost spending $(1 - \mu)$ will be directed towards unskilled labor demand.

According to Shepard's Lemma, differentiating the cost function with respect to the unskilled wage rate leads to:

$$L_{M,i} = (1 - \mu) \int_{k \in N_i} C_{M,i}(k) dk / w_{A,i}. \quad (20)$$

Given the tax rate by equation (11.1) and the resulting nominal wage by migration condition (16), skilled labor is calculated by equation (11) and $Y_i^{GDP} = (1 - t_i)Y_i$ to:

$$H_i = \left(\frac{t_i}{(1 - t_i)} Y^{GDP} \right) / w_{H,i}. \quad (21)$$

3.3 Steady State Equilibrium

Both economies are characterized by an initial equilibrium. Exogenous shocks such as trade liberalization lead to transition phases where countries and sectors are marked by fluctuations in firms and labor. Following Puga (1999), the adjustment process can be stated as:

$$\dot{N}_i = \lambda_1 \pi_{M,i}(N_1, N_2), \quad (22)$$

with \dot{N}_i as the derivative for the quantity of firms with respect to the adjustment time whilst reaching a steady-state equilibrium, λ_1 as a positive constant and N_i as a static variable. The share of unskilled labor in the manufacturing and agricultural sectors within countries is determined by industrial demand and will not be included in an explicit adjustment process. The same applies for skilled labor, as the share of skilled labor in the public R&D sectors between countries is determined by the migration condition.

For steady-state equilibrium to be stable, it is necessary that there is no incentive for fluctuation of firms. Therefore, both countries have a static share of firms, if

$$\frac{\partial \pi_{M,i}}{\partial N_i} \leq 0. \quad (23)$$

Hence, a higher number of firms do not lead to higher profits within a country.

From equation (23) follows that in steady state equilibrium firms are not making any profits through free market entry: $x_i = x_i^b = \alpha_i(\sigma - 1)/\beta$ in equation (7). The number of firms in country i is endogenously determined by equation (20):

$$N_i = \frac{L_{M,i}W_{A,i}}{(1-\mu)w_{A,i}^{(1-\mu)}q_i^\mu\alpha_i\sigma}. \quad (24)$$

The model and the equilibrium conditions are described by equations (1)–(24).

4 Theoretical Analysis: Economic Integration and Technology Diffusion

As usual for Computable General Equilibrium (CEG) models within the NEG-framework, the theoretical analysis focuses on steady state equilibria only. Hence, diminishing trade costs as to simulate economic integration of countries are exogenous shocks and lead to adjustments between steady state equilibria, but are not analyzed further. In general, there is a range of trade costs, which favor either a symmetric or an asymmetric distribution of industrial activity and lead to multiple equilibria.⁷ However, starting from an initial symmetric equilibrium and reducing trade costs continuously there is a single trade cost value from which a symmetric equilibrium switches to an asymmetric equilibrium and – with further trade cost reduction – vice versa.

Economic Development

To start with, I assume an initial symmetric equilibrium subject to high trade costs ($\tau = 3$), which do not differ between countries. Hence, both countries are characterized by equal shares of economic activity, i.e. manufacturing and research activity. To keep things simple, there is no difference in size and total factor endowment. Γ is the same in both countries and is assumed to 0.5. This means that 50% of domestic research is not applicable abroad or redundant. To stress out the impact of technology diffusion on economic development, results are compared to a model from Puga (1999), who did not consider R&D activity.

Figure 1 shows the share of industry, whereas Figure 2 illustrates the number of firms. The numerical results are shown in bold lines and labeled as “with R&D”. In addition, I use

⁷ Generally known as a Tomahawk bifurcation as the graphical presentation looks like a prehistoric tomahawk, see Fujita, Krugman and Venables (1999).

the model from Puga (1999) and simulate numerical results by the same parameter values and identical calibration. The corresponding results are in dash lines and labeled as “without R&D”.

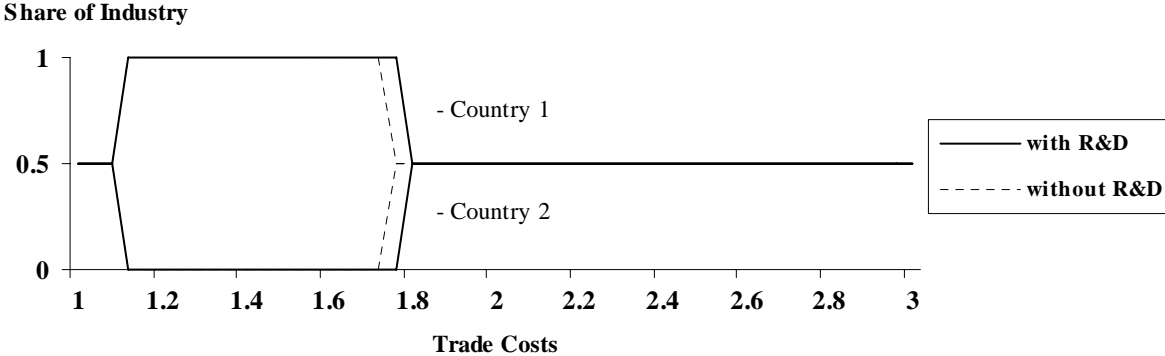


Figure 1: Shares of Industries

Usually, exogenous shocks such as diminishing trade costs lead to equilibrium interference and may change the status quo according to the presence and strength of the *pull* and *push forces*. However, if trade costs are still high and delivering markets abroad remains costly, firms do not cluster and therefore avoid higher competition on product and factor markets. As a result, the initial distribution of industry shares and therefore the symmetric equilibrium does not change.⁸

In the course of economic integration, further reduction of trade costs finally pushes the concentration of manufacturing activity as intermediate goods are less costly and firms face a higher demand, where other firms and consumers are located. The cost and demand linkages are now getting strong enough to dominate neoclassical product and factor market forces leading to a core-periphery pattern. As shown by both figures, the symmetric equilibrium dissolves towards an agglomeration of industrial activity in country 1. With a higher number of firms and products concentrated, the price index decreases in country 1 leading to an inward migration of skilled labor to its R&D sector. Hence, the transition phase is characterized by an erratic dislocation of industrial activity towards country 1 associated with a concentration of R&D activity. Compared to the numerical results from Puga (1999)’ model, agglom-

⁸ In general, diminishing trade costs reduce the price of imported goods and therefore the price index. All other things unchanged, a reduced price index leads by equation (24) to a higher number of firms in both countries as shown by a slight increase in Figure 2.

eration of industrial activity occurs earlier and is characterized by a higher number of firms during both, transition and agglomeration phases as shown in Figure 2.⁹

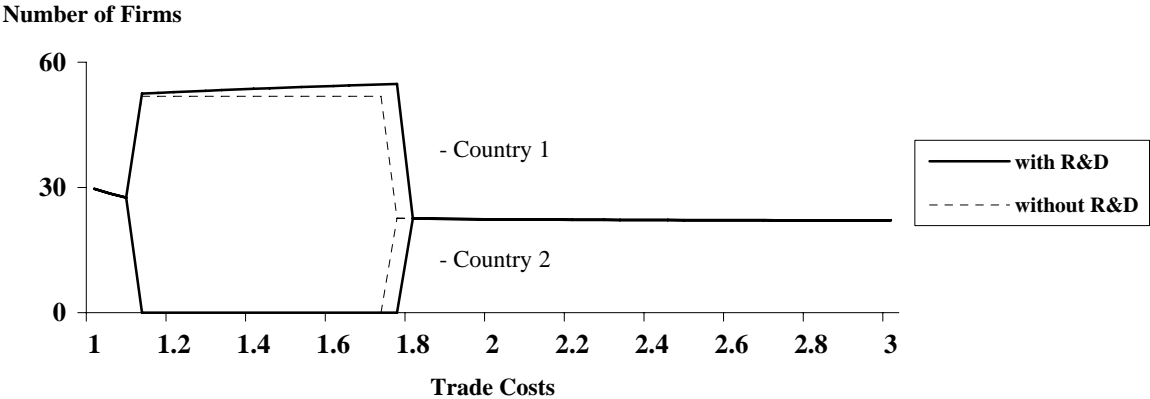


Figure 2: Number of Firms

Two level effects are important. First, there is an agglomeration effect due to increasing returns of scale at the industry level, which leads to a clustering of industrial activity and therefore to a higher number of firms. Second, as a result of inward migration of skilled labor, a concentration of R&D activity yields in a comparative cost advantage and increases the incentives for further agglomeration. As a result, self-reinforcing processes arise pushing industrial agglomeration and strengthening economic development.

In the aftermath of agglomeration ($\tau < 1.8$), further reduction of trade costs leads to a gradual increase of skilled workers and therefore R&D activity in country 2 – as lowering trade costs mainly benefit the structurally backward country by cheaper imported goods and therefore by a lower price index. As technology diffusion is restricted (or abundant), the move of skilled labor from country 1 towards country 2 results in a loss of technological knowledge to country 1’s firms. This leads by equation (24) to a decrease of the number of firms in country 1 as shown by Figure 2. However, the industrial agglomeration in country 1 remains stable. With respect to the results from Puga (1999)’s model, the number of country 1’s firm is still higher in country 1. Accordingly, within a NEG-framework, the explicit modeling of a R&D sector leads to an additional agglomeration effect and to a positive impact on economic development owing to its cost leverage effects. Finally, as trade costs tends to zero ($\tau = 1$), industrial concentration dissolves towards a symmetric distribution of industry shares creating the possibility for country 2 to catch up economically.

⁹ Numerical simulation also shows a higher industrial output in country 1, which is calculated by the multiplication of the number of firms with the break-even output.

To sum up, R&D activity pushes industrialization and strengthens economic development. Economic integration and technology diffusion leads to self-reinforcing processes favoring a core-periphery pattern of industrial dispersion, if trade costs still matters, but also creating the possibility for structurally backwards countries to catch up economically, if trade costs are low enough.

Technology Diffusion

Does the degree of technology diffusion change the impact on industrial agglomeration and economic development? Considering a global technological spillover effect for example, increased domestic R&D expenditure does not promote local economic development if countries benefit by the same way from technological knowledge. Or to put it differently, if R&D results are equally available and applicable, the location of innovation and research activity is not decisive for a core-periphery pattern to exist. Moreover, if technological knowledge from abroad is unrestricted available, economic development might be driven mainly due to foreign rather than domestic technological knowledge, especially for the case of structurally backward countries without significant investments in own R&D activity. Hence, in this context, the catching up process of structurally backward countries is positively related to the degree of technological spillover effect.

To deal with, I assume a core-periphery pattern subject to low trade costs ($\tau = 1.1$). Hence, manufacturing is fully whereas R&D-activity and therefore skilled labor is almost concentrated in country 1. Again, there is no difference in size and factor endowment with respect to immobile factors. Γ is the same in both countries and takes values between one (global spillover effect) and zero (local spillover effect). Economic integration is simulated by further trade cost reduction (i.e. from $\tau = 1.1$ to $\tau = 1.078$).

As discussed by Figure 1 and Figure 2, trade cost reduction and technology diffusion finally enables the periphery to catch up and trigger economic development at the core country's expense. Hence, I am interested in the critical value of the technological spillover effect as a benchmark from which a core-periphery pattern switches to a symmetric dispersion of industrial activity. Hence, technological spillover effects above (below) the critical value lead (stick) to a symmetric (an asymmetric) equilibrium where *push (pull) force* are dominant. Figure 3 plots the critical value of the technological spillover effect on the left scale as well as the corresponding numbers of firms in country 1 and country 2 on the right scale.

Figure 3 shows a range of trade cost ($\tau > 1.085$) where the core-periphery pattern still remains stable even in the case with a global spillover effect ($\Gamma = 1$): *pull forces* are still strong enough to ensure a stable asymmetric dispersion of industrial and R&D activity with all the firms concentrated in country 1, although both countries share the same technological knowledge.

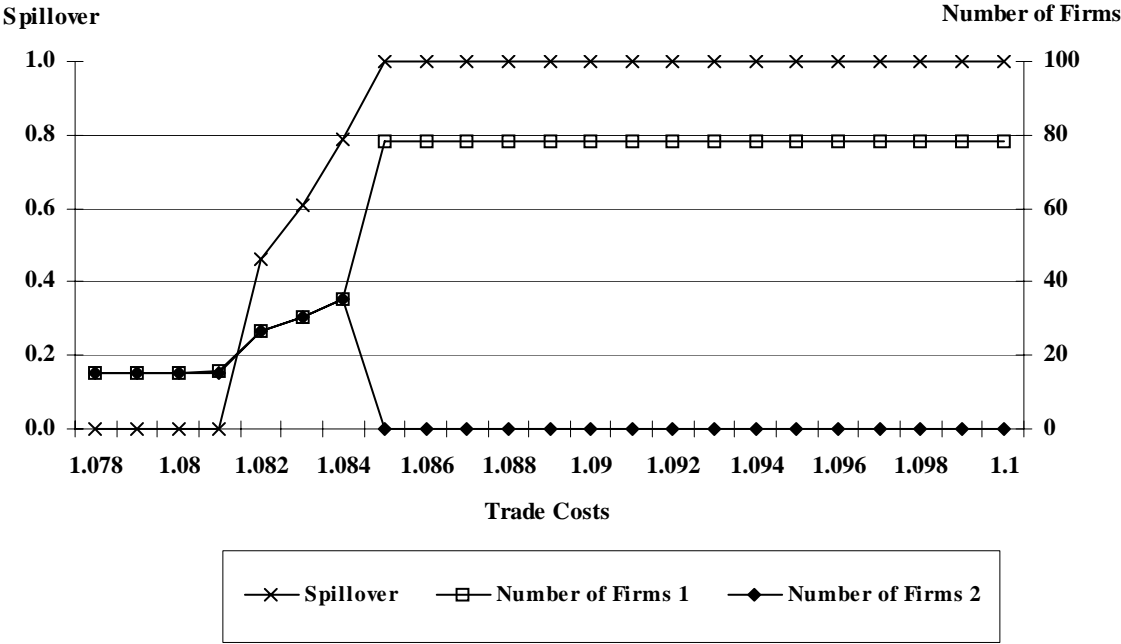


Figure 3: Spillover on Number of Firms and Nominal Output

However, further trade cost reduction ($\tau \leq 1.085$) combined with technology diffusion enables the periphery to trigger economic development and to attract firms at the core country's expense. Figure 3 shows the following relationship between trade cost reduction and technological spillover effect: the higher the trade costs, the higher the technological spillover effect as to switch a core-periphery pattern to a symmetric equilibrium – and therefore to create the possibility for country 2 to catch up economically. Hence with a high degree of technology diffusion, firms are dislocating from country 1 to country 2, where competition in factor and good markets is low but technological knowledge high. Since *push forces* getting stronger the further trade costs are reduced, the critical value for technological spillover effect and therefore the importance of technology diffusion to trigger economic development in country 2 decreases. Again, as trade costs tend to zero ($\tau \leq 1.081$), both countries have the same number of firms even in the case of local spillover effects ($\Gamma = 0$) and therefore regardless of technology diffusion.

As a main result, technology diffusion is shown to enable structurally backward countries to develop and to catch up economically especially under conditions, where an asymmetric dispersion of industrial activity still would exist if there is no technology diffusion.

5 Empirical Model: Technology Diffusion

This section introduces the regression equation to quantify foreign technology diffusion for the case of Greece, Portugal, Spain and Ireland ($i = 1, \dots, 4$). Let us first modify the right hand side of equation (9):

$$A_i = (S_i^d + S_i^f), \quad (25)$$

with $S_i^d = S_i$ and $S_i^f = \sum_{j \neq i} \Gamma_{ji} S_j$ for $j = 1, \dots, N$. The indices d and f indicate domestic and foreign R&D used in country i respectively. Note that Γ_{ji} defines country j 's technology diffusion rate to country i . Hence, A_i is determined by domestic and foreign R&D with the latter according to the technological spillover effect.

Next, consider the following aggregated production function:

$$Y_i = A_i * F_i(K_i, L_i), \quad (26)$$

where Y_i is aggregate output, K_i as capital and L_i as workforce are input factors. An increase of domestic and foreign R&D expenditure – used as a proxy for A_i – augments the efficiency of input factors used in final output production. As a result, domestic input productivity and output are likely to increase and therefore pushing economic development. Hence, to analyze the impact of technological knowledge on economic development, one can define total factor productivity (TFP) as aggregated output divided by the functional form of input factors like in Coe and Helpman (1995).¹⁰ However, TFP figures are susceptible to calculation and measurement errors and estimated coefficients might be less reliable due to inherent biases. Due to the more reliable data on labor input and to a lack of data for an adequate stock of business sector capital, I prefer to use labor productivity (LP) instead of TFP .

¹⁰ Coe and Helpman (1995) assume a Cobb-Douglas functional form with constant returns and define TFP as output divided by input factors according to their elasticity.

5.1 The Regression Model

Taking into account the time dimension, the regression equation for LP is stated as:

$$\log LP_{i,t} = \log A_t = \alpha_i + \alpha_i^d \log S_{i,t}^d + \alpha_i^f b_{i,t} \log S_{i,t}^f + \varepsilon_{i,t},$$

$$t = 1, \dots, T, \quad (27)$$

where i is country and t is time index, $S_{i,t}^d$ and $S_{i,t}^f$ represents domestic and foreign R&D capital stock in country i and $\varepsilon_{i,t}$ is the error term. The term $b_{i,t}$ captures intensity of foreign technology diffusion. The right hand side of equation (27) is a proxy for the unobservable technological knowledge.

Definitions of Variable

With respect to the domestic R&D capital stock, I follow Coe and Helpman (1995) and use the perpetual inventory method proposed by Griliches (1979) to calculate $S_{i,t}^d$. Turning to the foreign R&D capital stock and its intensity, definitions of $S_{i,t}^f$ and $b_{i,t}$ differ according to the channel used for technology diffusion – as described by Hafner (2007).

For the case of patent (P)-related spillover effects, foreign R&D capital stock is defined as the patent weighted average of domestic R&D capital stocks from abroad:

$$S_{i,t}^f \equiv S_{i,t}^{f,P} = \frac{1}{\sum_{j \neq i} a_{ji,t}} \sum_{j \neq i} (a_{ji,t} S_{j,t}^d), \quad j = 1, \dots, N, \quad (28)$$

with $a_{ji,t}$ as patent application of country j in country i . The ratio of $a_{ji,t} / \sum_{j \neq i} a_{ji,t}$ defines the patent-related diffusion channel: Γ_{ji}^P .

Patent count data mainly serve to determine the direction rather than the intensity of technology diffusion. Hence, as discussed in Hafner (2007), I do not specify foreign technology intensity explicitly:

$$b_{i,t} \equiv b_{i,t}^P = 1. \quad (29)$$

To capture trade (M)-related spillover effects like in Coe and Helpman (1995), I define foreign R&D capital stock as the average of domestic R&D capital stocks from abroad weighted by bilateral import shares:

$$S_{i,t}^f \equiv S_{i,t}^{f,M} = \frac{1}{\sum_{j \neq i} m_{ji,t}} \sum_{j \neq i} (m_{ji,t} S_{j,t}^d), \quad j = 1, \dots, N, \quad (30)$$

where $m_{ji,t}$ is country i 's import from country j . In this case, the ratio of $m_{ji,t} / \sum_{j \neq i} m_{ji,t}$ defines the trade-related diffusion channel: Γ_{ji}^M . Coe and Helpman (1995) also propose the use of an additional measure to capture technology intensity and therefore openness to trade. Hence, a country that imports more relative to its GDP should benefit more from foreign R&D spillover effects given the same composition of imports and a similar trade pattern between countries. Accordingly, trade-related foreign technology intensity can be measured as:

$$b_{i,t} \equiv b_{i,t}^M = m_{i,t} / Y_{i,t}. \quad (31)$$

The procedure to determine foreign technology stocks differs in the case of FDI (F)-related spillover effects due to the lack of adequate bilateral FDI inflow data. Instead of calculating technology diffusion channels and relating them to domestic R&D stocks from abroad, I use aggregate FDI inflow data to calculate FDI inflow stocks:

$$S_{i,t}^f \equiv S_{i,t}^{f,F} = (1 - \delta) S_{i,t-1}^{f,F} + \sum_{j \neq i} FDI_{ji,t-1}, \quad j = 1, \dots, N, \quad (32)$$

with $FDI_{ji,t}$ as foreign direct investment from country j to country i and δ as a time- and country-invariant depreciation rate. Again, I use the perpetual inventory method to calculate the benchmark for FDI inflow stocks. As a result, equation (32) is a proxy of foreign technology diffusion by FDI and interpretation is different compared to equation (28) and (30). Therefore, I do not express FDI-related technology intensity explicitly:

$$b_{i,t} \equiv b_{i,t}^F = 1. \quad (33)$$

Patent-, Trade- and FDI-Related Spillover Effects

Finally, to discuss the overall picture of technology diffusion, I incorporate patent-, trade- and FDI-related diffusion channels as defined by equation (28)–(33) to equation (27). Hence, the equation for LP changes to:

$$\begin{aligned} \log LP_{i,t} = \log A_i = & \alpha_i + \alpha_i^d \log S_{i,t}^d + \alpha_i^{f,P} \log S_{i,t}^{f,P} \\ & + \alpha_i^{f,M} b_{i,t}^M \log S_{i,t}^{f,M} + \alpha_i^{f,F} \log S_{i,t}^{f,F} + \varepsilon_{i,t} \end{aligned} ,$$

$t = 1, \dots, T$. (34)

5.2 The Data

The data used to measure the impact of technology diffusion on LP is widely discussed in Hafner (2007). Hence, the reader is referred to this paper for further information about the data and the construction of figures. However, the data set used in this paper reduces to Greece, Portugal, Spain and Ireland as I am interested in technology diffusion to acceding European countries.

According to the literature, I use worked hours as labor input to determine labor productivity. Figures on labor productivity per hour worked in constant US\$ (PPP) are from the *Total Economy Database* provided by the Groningen Growth and Development Center (GGDC). Following Coe and Helpman (1995), I calculate LP as indexed figures.

The OECD has published data on BERD since about 1965 mainly for the G7 countries as well as for Switzerland. In order to get a data set for all OECD countries from the beginning of 1965, one has to estimate missing R&D expenditure figures like Coe and Helpman (1995) did. However, the lack of R&D data as well as missing patent figures limits foreign technology diffusion to 20 OECD countries ($N = 20$)¹¹ and to 1981-2001. Hence, to get a complete picture of technology diffusion, I do not restrict the analysis to European core countries as the source of foreign technology. Converting R&D expenditure flows into R&D capital stocks; I use the perpetual inventory method and follow the procedure suggested by Griliches (1979). The R&D expenditure data in million constant US\$ (PPP) is from the OECD *Main Science and Technology Database*.

¹¹ The 20 OECD countries are respectively: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Mexico, Netherlands, Norway, Portugal, Spain, Sweden, United Kingdom, and USA.

As discussed, I use country specific patent data as one of the main technology diffusion channels. Since 1975, the WIPO offers annual figures on foreign patent application and grants broken down by and for each country (*Industrial Property Statistics Publication B Part I*). I prefer to use patent applications as figures based on patent applications instead of grants are more reliable and complete.

For trade- and FDI-related spillover effects, I use data published by the OECD in the *Monthly Statistics of International Trade* and the *International Direct Investment Statistics*, respectively. To relate domestic R&D capital stocks to bilateral trade patterns, I use figures on import as well as on GDP in million current US\$. GDP data (market price, value) is from the *OECD Economic Outlook Database*. To generate FDI inflow capital stocks, I apply once again the perpetual inventory method.

5.3 Unit Roots, Cointegration and the Error Correction Model

In general, productivity as well as R&D expenditure data exhibit a clear trend and unit root tests confirm nonstationarity, whereas the error term of the long-run regression equation may or may not be stationary. If the error term is stationary, variables are cointegrated and there is a common trend binding all variables. If not, the estimated relationship is spurious and no long-run relationship between variables exists. Moreover, the cointegration literature does not assume strictly exogenous regressors.

To start with, I first use the augmented Dickey-Fuller unit root test (ADF) from Fuller (1976) and Dickey Fuller (1979) to test for nonstationarity. The time series are assumed to be trended with an intercept and to have auto correlated error terms. For unit roots, the ADF test proposes a null hypothesis of nonstationarity against the alternative hypothesis that the time series is stationary. Test statistics are compared to asymptotic quintiles from Fuller (1976). Next, given nonstationarity of the data, cointegration can be tested either by applying (ADF) unit root tests to the remaining error term of the long-run relationship or by using test statistics of the lagged error correction term in the EC-model. Test statistics are compared to the asymptotic quintiles from MacKinnon (1991) in the first case and to Banerjee, Dolado and Mestre (1998) in the latter case. According to the literature, tests statistics for cointegration from the EC-model are more reliable than from the ADF testing procedure – at the expense of the assumption of exogeneity of the regressors. However, I use both methods to test for cointegration.

Once confirmed that the data have unit roots and are cointegrated, the EC-model from Engle and Granger (1987) allows quantifying properly the long-run relationship between productivity and R&D activity.

6 Empirical Results

To estimate the long-run relationship between cointegrated variables, I follow the procedure proposed by Engle and Granger (1987) and analyze first whether individual time series data are integrated by the same degree or not. In the case of unit roots, the next step is to test the cointegrated relationship by applying (ADF) unit root tests to the remaining error term of the long-run relationship or by using test statistics of the lagged error correction term in the EC-model. Finally, if variables are cointegrated, the EC-model allows estimating the long-run relationship between labor productivity and R&D activity properly accounting for serial correlation and endogeneity issues.

Test results from the ADF test are given in Table 1 for each country and any variable of the left and right hand side of equation (27).

Table 1: ADF Test by Fuller (1976) and Dickey Fuller (1979)
(Annual data for Greece, Portugal, Spain and Ireland from 1981-2001)

Intercept and Time-Trend:	$\log LP$	$\log S^d$	(28)/(29): $\log S^{f,P}$	(30)/(31): $b^P \log S^{f,M}$	(32)/(33): $\log S^{f,F}$
Greece					
ADF, Lag(1)	-1.331 (0.88)	-3.646 (0.03)	-1.557 (0.81)	-1.626 (0.78)	-2.239 (0.46)
ADF, Lag(2)	-1.516 (0.82)	-2.077 (0.56)	-2.503 (0.33)	-1.194 (0.91)	-4.140 (0)
Portugal					
ADF, Lag(1)	-3.556 (0.03)	-4.230 (0)	-3.146 (0.1)	-2.346 (0.41)	-2.677 (0.25)
ADF, Lag(2)	-1.465 (0.84)	-1.346 (0.88)	-1.747 (0.73)	-1.835 (0.69)	-3.168 (0.09)
Spain					
ADF, Lag(1)	-1,261 (0.9)	-2.583 (0.29)	-2.226 (0.48)	-2.796 (0.2)	-2.940 (0.15)
ADF, Lag(2)	-0.64 (0.98)	-2.607 (0.28)	-3.590 (0.03)	-2584 (0.29)	-2.590 (0.28)
Ireland					
ADF, Lag(1)	-1.784 (0.71)	-4.150 (0)	-1.857 (0.68)	-2.924 (0.15)	-0.168 (0.99)
ADF, Lag(2)	-0.930 (0.95)	-1.698 (0.75)	-1.583 (0.80)	-1.863 (0.67)	1.166 (1)

Notes: Test statistics are compared to the asymptotic quintiles from Fuller (1976). The p -values are in parentheses. The null hypothesis is nonstationarity while the alternative hypothesis is that the time series is stationary. The time series are assumed to be trended with an intercept and to have auto correlated error terms.

As discussed, the null hypothesis for the ADF testing procedure is nonstationarity while the alternative hypothesis is stationarity. I assume two different lag structures. As an overall result, *t*-statistics confirm nonstationarity of the data for each country either for one or two lags since the null hypothesis of unit roots can not be rejected. Hence, with unit roots for each variable, the analysis turns to the cointegration test procedures.

Table 2 shows *t*-statistics from cointegration test procedures obtained by the EC-model and by the ADF test for each country and for four different scenarios of technology diffusion: first, patent-related spillover effects, second, trade-related spillover effects, third, FDI-related spillover effects, and fourth, patent-, trade and FDI-related spillover effects. Unfortunately, both testing procedures confirm cointegration – at least at a 10% level and for ADF Lag (1) – only for Portugal but not for Greece, Spain and Ireland.

Table 2: Cointegration Test Results by the EC-Model^a and ADF^b; Patent-, Trade- and FDI-Related Spillover Effects

(Annual data for Greece, Portugal, Spain and Ireland from 1981-2001)

Equation:	(27) with (28)/(29)	(27) with (30)/(31)	(27) with (32)/(33)	(34)
Greece:				
t-stat. lagged error term	-2.64	-1.59	-1.41	-3.28
ADF, Lag (1)	-2.515	-1.553	-1.492	-1.7724
ADF, Lag (2)	-1.950	-1.647	-1.245	-1.587
Portugal:				
t-stat. lagged error term	-4.60***	-6.04***	-4.07***	-6.35***
ADF, Lag (1)	-4.263**	-4.192**	-3.970**	-4.404*
ADF, Lag (2)	-1.959	-2.6	-1.912	-2.813
Spain:				
t-stat. lagged error term	-2.90	-3.44*	-2.22	-2.69
ADF, Lag (1)	-3.050	-2.766	-3.196	-2.925
ADF, Lag (2)	-2.598	-2.430	-1.712	-2.568
Ireland:				
t-stat. lagged error term	-3.65**	-2.72	-2.96	-2.68
ADF, Lag (1)	-2.918	-2.423	-3.122	-3.021
ADF, Lag (2)	-2.46	-3.002	-2.463	-3.426

Notes: * (**) [***] denotes that cointegration is statistically significant at a 10% (5%) [1%] level.

^a Test statistics are compared to the asymptotic quintiles from Banerjee, Dolado and Mestre (1998) for two and four I(1)-regressors. Regressors used in the EC-model are assumed to be exogeneous.

^b By definition, the unit root equation for the resulting error term from the long-run relationship does not include a constant nor a time trend. Test statistics are compared to the asymptotic quintiles from MacKinnon (1991) for two and four I(1)-regressors. The null hypothesis is no cointegration, while the alternative hypothesis is that there is cointegration. * (**) [***] denotes that cointegration is statistically significant at a 10% (5%) [1%].

Hence, estimates of the long-run relationship between productivity and R&D activity and therefore of technology diffusion reduce to Portugal. I therefore skip Greece, Spain and Ireland from further analysis as their estimated results would be spurious and not reliable. Coefficients for Portugal are given in Table 3 according to the scenario of technology diffusion.

The corresponding t -statistics are reported in parenthesis. Starting with the impact of domestic R&D capital stock on labor productivity, estimated coefficient are significant, at least at the 5% level, and vary between 0.13 and 0.30 percent: a one percent increase of domestic R&D spending increases labor productivity accordingly. These coefficients are fairly comparable to other studies like Coe and Helpmann (1995) or Kao Chiang and Chen (1999) taking into account that these authors used the same approach but for panel data.

Turning to the impact of foreign R&D capital stock, I find empirical evidence of foreign spillover effects only for bilateral trade as technology diffusion channel. Hence, a one percent increase in R&D spending abroad raises labor productivity either by 0.21 percent (equation (27) with (30)/(31)) or by 0.19 percent (equation (34)). The corresponding t -statistics are significantly large and foreign R&D capital stock transferred by bilateral trade is significant at the 1% level. Moreover, technology diffusion induced by foreign patents or FDI is not significant leading to bilateral trade as the only source of technology diffusion for Portugal.

Table 3: Labor Productivity Estimation Results for Portugal by the EC-Model; Patent-, Trade- and FDI-Related Spillover Effects

(Annual data for Portugal 1981-2001)

Equation:	(27) with (28)/(29)	(27) with (30)/(31)	(27) with (32)/(33)	(34)
EC-Model:				
$\log S^d$	0.27 (2.82)**	0.186 (4.31)***	0.295 (2.62)**	0.131 (2.31)***
$\log S^{f,P}$	0.07 (0.53)			0.115 (1.64)
$b^M \log S^{f,M}$		0.213 (3.14)***		0.189 (3.15)***
$\log S^{f,F}$			0 (0.25)	0 (-0.16)
R^2	0.598	0.706	0.458	0.818

Notes: The t -statistics of the coefficients are reported in parentheses. * (**) [***] denotes that the coefficient is significantly different from zero at a 10% (5%) [1%] level. All equations include unreported country-specific constants.

7 Conclusion

Research activity and its technological spillover effects are shown to be crucial for structurally backward countries within integrating regions to catch up economically. In such regions, countries face international competition not only for firms but also for mobile factors such as skilled labor whereas technological knowledge is believed to spur economic development in general. However, technology diffusion and the inclusion of foreign technological knowledge may have a different impact between countries. While for industrialized countries a high degree of technology diffusion may result in a loss of industry shares and mobile factors,

structurally backward countries certainly gain by technology diffusion – as shown by the theoretical analysis. It turns out to be essential for structurally backward countries to gain access to technological knowledge and to attract human capital as to increase industrial activity and to upgrade local industries. Hence, the greater the access to foreign R&D and skilled labor is, the higher the possibilities to close the gap toward the technological frontier and to participate in world markets are.

Is it all about technology and investing in R&D? Well, competing globally (or regionally) for market shares and in factor markets, the answer is definitely yes for industrialized countries. For structurally backward countries – facing competition not only with developed regions/countries but also amongst each other – the answer is also yes at least for the long-run. While industrialized countries keep their status quo by investing in R&D and relying on advanced technology and high-quality products, the developing path for structurally backward countries may lead via low cost (labor-) intensive manufacturing to upgraded industrial activities in specific sectors. However, still more work on the interaction of agglomeration effects, factor mobility and technological spillover effects needs to be done, especially to deal with the increasing pressure for unskilled labor migration from poor to rich countries (Lundborg und Segerstrom, 2002) or to analyze factor mobility restrictions reimposed as to protect industrialized countries and their labor markets (Ottaviano und Thisse, 2002).

Returning to the catching-up process of countries acceding to the EU in the 1980s and 1990s, the empirical part of the paper analyzes the impact of technology diffusion by the use of time series data for Greece, Portugal, Spain and Ireland from 1981-2001. In considering three different technology diffusion channels, estimates, however, reduces to Portugal as test procedures confirm nonstationarity and cointegration only for this country. I find empirical evidence for foreign spillover effects determined by bilateral trade: a one percent increase in R&D spending abroad raises labor productivity in Portugal between 0.19 and 0.21 percent. Additionally, estimates shows that there are no significant spillover effects from foreign patent applications or from FDI inflows. Looking on macro data once again, Portugal's gross domestic expenditure on R&D (GERD) per GDP, for example, increased from 0.26 to 0.84 percent between 1980 and 2001, whereas the share of the EU-core countries, as calculated by Hafner (2006), increased from 1.76 to almost 2 percent. As the R&D expenditure gap of Portugal compared to the EU-core countries still remains large, the inclusion of foreign technological knowledge due to bilateral trade must be a crucial factor to spur Portugal's economic development.

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Appendix

Specific details on parameters and numerical simulation are listed in the appendix (A) whereas further information about the data is given by appendix (B).

(A) Numerical Simulation and the Choice of Parameters

Numerical simulations are calculated in Gauss. Programming codes are freely available upon request. The parameters for numerical simulation are set to $\mu = 0.6$, $\sigma = 6$, $\iota = 0.6$, $\gamma = 0.3$ and $\theta = 0.8$. Original total factor endowment of unskilled and skilled labor as well as of agricultural land is assumed to be the same for both countries. Both countries have the same technology. Technological spillover effect varies by $\Gamma \in (0,1)$ and β is normalized to $\beta = \rho = (\sigma - 1)/\sigma$. Due to calibration reasons, the parameter for firms' fix costs is set to $\kappa = 1/8$.

The methodology for numerical simulation follows Puga (1999): based on the prior determined number of operating firms N_i , the price index q_i and nominal wages $w_{A,i}$ of unskilled labor is calculated for a short-run equilibrium. Concurrently, the share of unskilled labor in manufacturing $L_{M,i}$ and in agriculture $L_{A,i}$ as well as of skilled labor H_i in R&D sectors can be determined. The number of firms is varied and migration and production decisions are adjusted until equation (23) is satisfied. In a long-run equilibrium there is no further incentive for firms to fluctuate or for labor to migrate.

(B) R&D Capital- and FDI Inflow Stock Data

To convert flow figures into stock variables, I apply the perpetual inventory method as proposed by Griliches (1979). Hence, I use aggregated R&D expenditure as well as FDI inflow data from Hafner (2007) and calculate stock variables with a country- and time-invariant depreciation rate of 10%.¹²

Table B.1 lists figures for R&D capital stocks in million constant US\$ (PPP) and Table B.2 lists figures for FDI Inflow Stocks in million current US\$ (PPP). Figures are given for Greece, Portugal, Spain and Ireland.

¹² The reader is referred to the paper for further details and assumptions.

Table B.1: R&D Capital Stock Data

(BERD Expenditure in million constant US\$ (PPP))

	R&D Expenditure Data			R&D Flow	R&D Stock
	Available	Avg. Growth	Ann. Growth	1981	Benchmark
Greece	1981-2001	7.837	10.843	46.079	221.076
Portugal	1981-2002	9.820	11.492	53.01	246.648
Spain	1981-2002	5.534	8.489	797.862	4315.433
Ireland	1981-2001	7.985	10.946	109.359	522.094

Notes: The benchmark relates to the year 1981 for all countries and is calculated following the procedure suggested by Griliches (1979). Depreciation rate is assumed to 10%. Average growth factors and annual growth rates (%) are calculated over the period, where R&D expenditure data was published.

Table B.2: FDI Inflow Stock Data

(FDI Inflow in million current US\$)

	FDI Inflow Data		FDI Expected Inflow			FDI Stock	
	Available	Ann.Growth	Period	Avg.Growth	Ann.Growth	Exp. Flow	Benchmark
Greece	1987-2003	-3.937	1987-1990	1.364	10.907	1464.52	7004.894
Portugal	1980-2003	19.136	1980-1990	19.274	34.431	77.979	175.508
Spain	1980-2003	14.279	1980-1990	11.621	27.798	959.252	2537.825
Ireland	1983-2003	25.637	1983-1990	0.869	-1.978	285.417	3558.046

Notes: The benchmark relates to the year 1987 for Greece, to 1983 for Ireland and to 1980 for Portugal and Spain. Depreciation rate is assumed to 10%. The expected flow as well as their corresponding average growth factors and annual growth rates (%) are calculated for the period given by the table.