Sources of TFP Growth in a Framework of Convergence-Evidence from Greece

Ioannis Bournakis

Department o f Economics and Statistics, Middlesex University, London, UK

The Burroughs, Hendon, NW4 4BT, Email: I.Bournakis@mdx.ac.uk

Sources of TFP Growth in a Framework of Convergence-Evidence from Greece

The main hypothesis tested in the paper is whether technology is a conduit of productivity growth for a country that falls behind the frontier. Although the current analysis focuses on a country growth narrative, the evidence represents a pair of countries (i.e. Greece and Germany) that admittedly form the periphery and the core of Europe. The first lesson taken from the study is that for more than two decades the speed of productivity adjustment was rather low in Greece underlying a number of unobserved rigidities that exist both at the industry and the institutional level. Even though the speed of technology transfer is low, the adoption of foreign technology remains an important source of productivity growth. Other key findings are that productivity gains from trade exist but their full realization requires a substantial time lag. Additionally, the degree of trade openness improves absorptive capacity confirming the dual role of trade as recently stressed in the productivity literature. R&D activity is another productivity growth contributor but only through higher rates of innovation.

Keywords: Productivity Growth, Productivity Convergence, Trade, R&D, Greece, Germany, Manufacturing

Introduction

From Solow's (1957) seminal work on economic growth, technology is recognised as the main source of economic growth. The question that still remains of particular interest is what drives technological progress and more importantly what affects countries' ability to imitate technology already developed somewhere else. Abramovitz (1986) notes that the main target of less industrialised countries during the second half of the last century was to incorporate unexploited technology used in advanced countries into their production processes. In conformity with this view, the successful adoption of foreign technology is a convincing explanation for successful productivity catch-up. Needless to say, the role of technology diffusion is yet more important for countries that fall behind technologically. Accordingly, empirical research is driven by our need to understand either the factors that contribute to a faster technology transfer (Cameron et al. (2005)) or the barriers that slow the adoption process leading to productivity disparities around the world (Parente and Prescott (1994)).

The present paper offers an analytical narrative that contributes to the productivity convergence debate. The paper focuses on Greece and Germany, with Greece the technological "follower" country and Germany the technological "frontier". Within this set up, the study explores the sources of productivity growth in the Greek manufacturing sector paying special attention to technological catch-up. The main proposition is that the further Greece's productivity falls behind Germany's the higher the potential for technology transfer and hence the faster the pace of productivity growth. At a later stage, when convergence has been implemented productivity growth of the "follower" country slows down, the potential for further technology transfer is limited.[1]

The selection of countries seeks to stress Germany's technological leadership as well as its strong trade relationships with Greece. Note Germany, apart from a technologically pioneer country in the global economy, is also the major trading partner of Greece. A strong bilateral trade relationship motivates us to investigate whether trade is an important conduit of technology transfer. Our strategy to investigate the sources of productivity growth in Greece follows three main steps. First, we model the determinants of productivity growth using considerations from various sections of the literature; second, we proceed with an exercise of growth accounting to obtain a measure of Total Factor Productivity (TFP), which is our approximation of technology and third, we use an econometric specification to evaluate the impact of various determinants on TFP growth.

The paper focuses especially on R&D and trade as potential productivity shifters due to their duality in a technological transfer framework. Griffith et al. (2003) suggest that trade and R&D can promote productivity growth either via high rates of learning and innovation or via improvements in a country's absorptive capacity. Notice, our approach takes also into account domestic market conditions, such as labour market rigidities and the degree of domestic competition assessing their role on productivity performance.

The paper is organized as follows: section 2 provides a link of the current study with the voluminous productivity and growth literature. In a sub-section, we provide a discussion on key peculiarities of the Greek economy directly related to productivity performance. This discussion is designed to guide the reader on how the business environment in Greece has been influenced by institutional reforms. Sections 3 and 4 models and measures TFP growth within a convergence framework, respectively. Section 5 presents results from the benchmark econometric model as well as results from further specifications. Section 6 concludes.

Theoretical Considerations

Sources of TFP Growth: A Short Overview

Bernard and Jones (1996a, 1996b) specified a model for the sources of productivity growth as a function of technological transfer. Griffith et al. (2004), Cameron (2005), Cameron (2006) and Khan (2006) adopted this model to explore the sources of TFP growth in manufacturing using data from OECD countries. These papers address the importance of technological transfer from the frontier economy.[2] The existing literature focuses on advanced economies and lacks evidence from technologically laggard countries, where the potential of technological transfer is evidently greater. With our paper, we attempt to cover this empirical gap as Greece, although an OECD country still belongs to the economic periphery of the European Union.

The influence of innovation on productivity growth through investment in R&D is documented in Griliches (1980) and Griliches and Lichtenberg (1984) among many others that confirm this positive link. The above evidence relies on either firm or

[1] This implies that as a country closes the technology gap with the frontier then productivity growth is further stimulated from country's own efforts, such as domestic innovative activity, capital deepening and so forth. The analytical framework of the next section provides a more formal representation of this argument.

[2] The majority of these studies take US as the frontier country.

country level data to illustrate that domestic investment in R&D leads to cost reductions and thus to productivity improvements. Spence (1984), Helpman and Grossman (1991) and Coe and Helpman (1995) provided evidence on the multifaceted role of R&D confirming that a country can gain from its own R&D effort but can also exploit positive spillovers by imitating the R&D outcomes of other countries. A crucial issue is how the gains from R&D conducted abroad are distributed across countries. Keller (1998) confirms the scenario that foreign R&D is diffused to other countries via imports in capital assets and raw intermediate materials. Exporting is another channel that generates substantial positive spillovers. The static exporting benefit is the exploitation of economies of scale derived from market expansion. In a dynamic context, exporting brings producers into contact with international best practices (i.e. the learning-by-exporting hypothesis); although, the empirical support for this hypothesis remains vague. Evidence from Clerides et al. (1998) and Bernard and Jensen (1999a, 1999b) support the self-selection hypothesis, which suggests that good firms (in terms of productivity) are those that become exporters without further benefits from export involvement.[3]

Even if the domestic market can be benefited by foreign innovation, domestic R&D effort is essential for two different reasons. First, higher R&D expenditure accelerates the rate of innovation fostering productivity growth. Second, domestic R&D secures the existence of a minimum level of expertise that is necessary for the effective absorption of the foreign technological advancements. Cohen and Levinthal (1989) and Acemoglu and Zillibotti (2001) point out that investment in R&D and human capital stimulates domestic country's ability to assimilate and exploit existing information. Griffith et al. (2004) systematically address this issue in a panel of OECD countries, revealing that domestic R&D substantially improves the absorptive capacity of the domestic economy.

Labour Market Distortions and TFP Growth-The Case of Greece

Greek labour market is regarded as rather distorted with approximately 15-20 % of the Greek labour force during the 1980s to be in receipt of the minimum wage while during the same period the respective figure in the USA and France was 5% and 12% (Koutsogeorgopoulou (1994)). Greece has also one of the highest minimum to median wage in OECD indicating a heavily regulated labour market.[4] The national minimum wage in Greece is determined jointly by representatives of the General Confederation of Greek workers and the main employer organisations. The minimum rate of pay agreed becomes the basis for the contractual wages and salaries set by individual industries.

The tendency of the high minimum to average wage in Greece (see Neumark and Wascher (2004)) can be explained, first, by the presence of powerful trade unions that set a commonly agreed minimum wage much higher than the perfectly competitive wage in many industries and, second, by the implementation of a welfare program that attempted to narrow the income and wage inequalities having persisted in the Greek economy before 1980s. A part of the latter policy was the introduction of a minimum wage indexation, which made automatic pay adjustments (known as

---

[3] See Kraay (1999) and Castellani (2002) for firm level evidence that confirm a positive causal link from exporting to productivity.

[4] For the period 1980-2003, the highest minimum to median wages in OECD is in France and Greece with 0.6 and 0.55, respectively.

ATA[5]) compensating low income earners for erosion in wages due to inflation. This system was abolished in 1991 but trade unions have maintained a strong bargaining power in negotiating the determination of minimum wage.

The trade off between minimum wage policy and unemployment has attracted much attention so far but there is relatively less focus on the impact of minimum wage on productivity performance (Siebert (1997)).[6] A heavily regulated market is likely to prevent from a rapid and costless allocation of the labour inputs. In our case the resulted puzzle is as follows: influential trade unions raise minimum wages over time increasing unit labour costs surpassing thus productivity growth.

The degree of competition in the domestic market is another determinant of productivity performance. According to the traditional Schumpeterian notion, a competitive market ensures the reduction of slack, the promotion of innovation and high levels of efficiency. This scenario gains credibility from Vickers (1995), although where the competition-productivity link is highly endogenous an empirical confirmation becomes rather ambiguous. Nickell (1996) notes that there are theoretical reasons whereby competition may improve performance but the existing evidence can hardly be viewed as overwhelming. Caves (1987) supports the view that market efficiency is independent from the degree of concentration converging on Jovanovic's (1982) point that competition is not necessarily a vehicle of efficiency itself, but instead allows many flowers to bloom but only the best to survive, and such a process is infeasible in a monopolistic market.

Turning to the case of Greece, evidence on the competition-productivity relationship is limited. Anagnostaki and Louri (1995) and Fotopoulos and Spence (1997) reveal that Greece's accession to EU has resulted in a higher level of concentration in the manufacturing sector. A large number of exits of medium and small- sized enterprises was documented due to the severe competition induced from a highly integrated market. Although our conceptual model departures from a different point, our empirical analysis contributes to the nexus of minimum wage-productivity as well as to the nexus between market concentration and productivity.

Theoretical Considerations

Following the previous models in the productivity convergence literature (Bernard and Jones, 1996a, 1996b; Cameron et al., 2005) we consider a world with only two countries $c \in \{GRC, GER\}$, where the general form of the production function in industry i at time t is written as:

$$Y_{c,i,t} = A_{c,i,t} f(K_{c,i,t} L_{c,i,t}) \qquad (1)$$

Y measures value added and the inputs include capital stock K, labour L. Parameter A represents a measure of technical efficiency as in Solow's study, and differs across countries and industries. In the empirical analysis, the efficiency parameter is approximated by an index of Total Factor Productivity (TFP). The above production function is homogenous of degree one and exhibits diminishing marginal returns to the production inputs.

---

[5] ATA stands for the Greek acronyms of the Automatic Price Adjustment.

[6]In the likely case, that minimum wage slows down productivity this is reflected into higher levels of unemployment.

For the purposes of the present analysis, at a given point in time t, one of the countries c will have a higher level of TFP and thus this country is specified as the "technological frontier" economy (Cameron et al., 2005). In our study this country is Germany and it is indexed by *GER* while the follower economy is Greece denoted by *GRC*. A general formulation of the efficiency parameter A or equivalently TFP growth in industry i of country *GRC* is:

$$\Delta \ln A_{i,GRC,t} = \gamma_{i,GRC,t} + \lambda_{i,GRC} \ln\left(\frac{A_{i,GER,t-1}}{A_{i,GRC,t-1}}\right) \tag{2}$$

In equation (2) parameter γ represents the rate of innovation, which depends on industry-specific factors while parameter λ denotes the change in TFP with respect to technology transfer from the frontier. The ratio $\left(\frac{A_{i,GER,t-1}}{A_{i,GRC,t-1}}\right)$ indicates that the higher is the gap in industry i from the frontier economy the greater is the potential for productivity growth through technological transfer. For the frontier economy, productivity growth depends only on domestic innovation and thus the second term in the right-hand side of equation (2) is zero for the frontier economy

$$\Delta A_{i,GER,t} = \gamma_{i,GER,t} \tag{3}$$

Subtracting equation (3) from (2) yields the following relationship:

$$\Delta \ln\left(\frac{A_{i,GRC,t}}{A_{i,GER,t}}\right) = (\gamma_{i,GRC,t} - \gamma_{i,GER,t}) + \lambda_{i,GRC} \ln\left(\frac{A_{i,GRC,t-1}}{A_{i,GER,t-1}}\right) \tag{4}$$

Equation (4) can be viewed as an equilibrium correction model (ECM) with a long-run steady state relative TFP. Assuming that in the long-run, $\Delta \ln\left(\frac{A_{i,GRC,t}}{A_{i,GER,t}}\right) = 0$, the steady state equilibrium is given by:

$$\ln\left(\frac{A^{*}_{i,GRC}}{A^{*}_{i,GER}}\right) = \frac{\gamma_{i,GRC} - \gamma_{i,GER}}{\lambda_{i,GRC}} \tag{5}$$

Equation (5) states that in the steady state equilibrium, relative TFP depends on the rates of innovation in the non-frontier economy *GRC*, in the frontier economy *GER* and on the speed of technological convergence λ that occurs between the two economies.

A key inference that can be made from equation (5) is that country *GRC* remains technologically behind in steady state equilibrium as long as the technological frontier country *GER* maintains a higher rate of innovation: $\gamma_{i,GRC} < \gamma_{i,GER}$. Finally, the set of factors considered as drivers of $\gamma_{i,GRC,t}$ includes R&D, trade, and conditions in the labour and product market. Furthermore, R&D and trade also affect the speed of technological transfer $\lambda_{i,GRC,t}$. Appendix A displays some evidence to justify the selection of Germany as a comparator country, Appendix B describes the data sources and the definition of variables.

Measurement of TFP, Growth rates and Levels

Total factor productivity (TFP) indices are calculated from the Divisia number approach developed by Caves et al. (1982). The TFP index is derived directly from a flexible translog production function and it is superlative since it is a close approximation of an arbitrary, twice differentiable production function with constant returns to scale. The TFP growth in industry *i* in any country *c* is defined as:

$$\ln\left(\frac{A_{i,c,t}}{A_{i,c,t-1}}\right)=\ln\left(\frac{Y_{i,c,t}}{Y_{i,c,t-1}}\right)-a_{t,c}^{L}\ln\left(\frac{L_{i,c,t}}{L_{i,c,t-1}}\right)-(1-a_{t,c}^{L})\ln\left(\frac{K_{i,c,t}}{K_{i,c,t-1}}\right) \quad (6.1)$$

where *c*= Greece (*GRC*), Germany(*GER*)

Output *Y* is measured by value added, *L* is a measure of labour input and *K* denotes capital stock constructed by the perpetual inventory method that accumulates investment flows in capital assets. The labour share is initially defined as the ratio of labour compensation to value added and enters equation (6.1) in a weighted manner as $a_{c,t}^{L}=\frac{a_{i,c,t}+a_{i,c,t-1}}{2}$. The assumption of constant returns to scale production function implies that capital share is equal to one minus the labour share.

For the purposes of our analysis, we need to specify two different TFP indices. First, we need an index that compares the level of TFP between Greece and Germany and second, an index that measures the growth rate of TFP in each country.

The relative TFP index in industry *i* between Greece and Germany is defined as:

$$\ln\left(\frac{A_{i,GRC,t-1}}{A_{i,GER,t-1}}\right)=\ln\left(\frac{Y_{i,GRC,t-1}}{Y_{i,GER,t-1}}\right)-a_{GRC,t}^{L}\ln\left(\frac{\tilde{L}_{i,GRC,t-1}}{\tilde{L}_{i,GER,t-1}}\right)-(1-a_{GRC,t}^{L})\ln\left(\frac{\tilde{K}_{i,GRC,t-1}}{\tilde{K}_{i,GER,t-1}}\right) \quad (7)$$

$\tilde{L}$ is an index that allows us to control for differences in the quality of labour input. More precisely, we define:

$$L_{i,GER,t}=\sigma_{i,t}^{j}\ln L_{i,GER,t}^{j},\; L_{i,GRC,t}=\sigma_{i,t}^{j}\ln L_{i,GRC,t}^{j}, \quad (7.1)$$

where *L* represents the annual total hours worked for each group *j* and σ stands for the share of each group to total number of hours. This adjustment is necessary as the composition of labour changes over time affecting, thus the real contribution of labour input to productivity.[7] The classification of labour groups is based on educational characteristics[8] as follows: (i) high-skilled (University graduates), (ii) medium-skilled

[7] A shift from low to high skilled labour results in an increase in output growth (Jorgenson et al. (2005)). Table 1 shows that the proportion of low quality workers in Greek manufacturing industries has decreased clearly indicating that the growth accounting needs to decompose labour input accordingly.

[8] In the period under study, the educational systems between Greece and German are identical so the classification of workers in different groups is perfectly consistent. The reader can find further insights regarding the construction of labour quality indices from the EUKLEMS Growth and Productivity Accounts manual.

(Intermediary Education graduates) and (iii) low-skilled (no formal educational qualifications). We choose the original labour share a_{GRC} in equation (7) instead of a weighted measure of labour share as followed by Redding et al. (2005) to avoid issues related to the direction of technological change. The first two columns in Table 1 show that the level of labour intensity is different between the two countries, implying that the available technology in the two countries might drive the input mixes at the industry level. Furthermore, the type of labour used in the two countries also varies with Germany to be more medium-skilled labour intensive (i.e. 62%) while Greece to be low-skilled labour intensive (i.e. 64%). It is beyond the scope of the current paper to explore the existence of differences in labour input mixes but it is sufficient for our analysis to adjust TFP measures for a non-homogenous labour factor.

Capital input is a stock measure adjusting for the degree of actual utilization. The original capital stock is generated via the inventory perpetual method as follows: $K_{i,c,t} = (1-\delta)K_{i,c,t-1} + I_{i,c,t-1}$, where δ is the depreciation rate, defined at the constant rate of 10% for all industries and I denotes investment in fixed capital assets. The latter includes compensation only for the services of fixed reproducible assets. This means that inventories are excluded from the group of fixed capital assets. Although the omission of this component is purely driven by data unavailability, we think that any potential problem is of minor importance. As it is widely accepted inventories are only short-term cycles without trends over longer periods so growth accounting results are not affected.[9] The investment flows are converted into constant 1995 prices using gross fixed capital formation deflators taken from OECD-Economic Outlook database.[10] The series of capital stock is initialised with the following formula: $K_{i,c,1980} = \frac{I_{i,c,1980}}{g_i + \delta}$, where g is the average growth rate of industry i's investment over the whole period and the subscript 1980 indicates the first year with available investment data.

Capital stock is not always utilised at full capacity rate, instead there are short-term fluctuations that follow largely the aggregate business cycle. An unbiased measure of TFP needs to remove the effect caused from the short-term fluctuations in the utilisation of capital. Hall (1990) proves that the exogeneity condition of Solow residual fails when capital stock is under (over)-utilised leading to an over (under)-estimated TFP measure. In the present paper, we adjust capital stock for effective use applying a rate of capacity utilisation taken from the Business Tendency Surveys of OECD-Main Economic Indicators database. Capacity utilisation is assessed with reference to the use of fixed capital assets such as buildings, plants, machinery and vehicles.[11] The effects of cyclical variations of capital are removed by multiplying the

---

[9] The current capital account does not also include land compensation. To the best of our knowledge, there are not available data concerning the rates of return on land at the industry level implying that this issue cannot be effectively tackled within the existing data resources

[10] The investment deflator index is country specific, a feature that does not takes into account that the formation of capital assets vary across industries and thus the price movements of these assets might differ substantially over time. Nonetheless, the present aggregate deflator is the best alternative solution, given the shortage of data for different types of assets along with the lack of industry specific investment deflators.

[11] The survey of capacity utilisation takes place on a quarterly basis and refers to the aggregate manufacturing sector. The reader can find further details about the calculation of the rate of capacity utilisation in the OECD manual (Business Tendency Surveys Handbook).

actual capital stock with the rate of capacity utilisation: $\tilde{K}_{i,c,t} = u_{c,t} K_{i,c,t}$, where u denotes the percentage rate of capacity utilization.

The index that measures the growth rate of TFP takes the following form:

$$\ln\left(\frac{A_{i,c,t}}{A_{i,c,t-1}}\right) = \ln\left(\frac{Y_{i,c,t}}{Y_{i,c,t-1}}\right) - a_{c,t}^{L} \ln\left(\frac{L_{i,c,t}^{j}}{L_{i,c,t-1}^{j}}\right) - (1 - a_{c,t}^{L}) \ln\left(\frac{\tilde{K}_{i,c,t}}{\tilde{K}_{i,c,t-1}}\right) \quad (8)$$

The definition of labour index takes a translog form as suggested by Young (1995):

$$\ln\left(\frac{L_{i,c,t}}{L_{i,c,t-1}}\right) = \sum^{3} \bar{\sigma}_{i,c}^{j} \ln\left(\frac{L_{i,c,t}^{j}}{L_{i,c,t-1}^{j}}\right) \quad (8.1)$$

where σ denotes the weighted share of labour compensation of each group j in total labour compensation and defined as $\bar{\sigma}_{i,c}^{j} = \frac{\sigma_{i,c,t}^{j} + \sigma_{i,c,t-1}^{j}}{2}$. The labour input L of each group j is measured, as before, by the annual total hours worked.

The data used for the calculation of TFP are taken from EU KLEMS. OECD-STAN is used as a complementary source. Both databases are constructed in a fully compatible manner from Supply and Use tables (SUTs) derived from the National Accounts system. In our analysis, we rely more on EU KLEMS (2007) as it provides data for labour decomposition that are essential for a consistent and adequate productivity measure.

A further issue concerning the construction of indices (7) and (8) is to convert valued added, labour compensation and investment into a common currency. O' Mahony (1996) shows that relative TFP levels vary substantially according to the conversion factor used. For our analysis, we obtain an aggregate Purchasing Power Parity (PPP) exchange rate based on prices of final expenditure from the World Bank Development indicators (International Comparison Project (ICP)) to convert data into international USD. This aggregate exchange rate conversion factor is the best available option taking into account that industry-specific exchange rate is difficult to find. After converting data into a common currency, we adjust value added data into 1995 constant prices using industry-specific price deflators.

Columns (5)-(7) in Table 1 show TFP growth rates and relative TFP levels of the aggregate manufacturing sector for Greece and Germany. The reported values show that the Greek manufacturing sector has grown on average by 7.35% while the German manufacturing has clearly experienced a lower rate of productivity growth equal to 0.45%. This preliminary evidence reveals that the non-frontier country tends to grow faster offering support to the core proposition of the neoclassical theory of convergence. The RTFP figures in the last column of Table 1 can be interpreted as follows: in 1980, Greek manufacturing is only 5.39% as productive as the German counterpart is, while in the last year of the sample relative TFP level has increased to almost 24%. Another interesting remark of Table 1 is that Greece experiences quite rapid growth rates during 1980s whereas there is a slow down in the second decade of the sample, which explains to a large degree why the technological gap between the two countries, remains large.

Table 1. Growth Rates and Relative Levels of TFP

Year	*Labour Share Greece*	*Labour Share Germany*	*Low-skilled Labour Greece*	*Medium-Skilled Labour Germany*	$TFPG_{GER}$	$TFPG_{GRC}$	*RTFP*
	1	2	3	4	5	6	7
1980	73.1%	80.3%	83.4%	59.4%			5.4%
1981	73.3%	78.9%	81.8%	59.7%	-4.6%	7.7%	6.1%
1982	74.9%	77.7%	80.1%	59.9%	-2.5%	16.1%	7.7%
1983	69.3%	77.0%	78.4%	60.1%	-0.2%	14.3%	10.0%
1984	70.2%	75.8%	76.8%	60.4%	-1.0%	15.0%	12.5%
1985	68.4%	74.3%	75.1%	60.6%	-0.3%	13.5%	16.0%
1986	70.1%	78.2%	73.4%	60.8%	-1.2%	1.1%	14.0%
1987	65.3%	76.4%	71.8%	61.0%	-4.3%	7.5%	18.2%
1988	67.8%	75.3%	70.1%	61.3%	0.6%	7.6%	17.9%
1989	68.0%	76.8%	68.4%	61.5%	1.8%	8.2%	18.9%
1990	64.5%	77.9%	66.8%	61.7%	0.5%	8.1%	22.6%
1991	65.3%	80.8%	65.1%	61.7%	2.0%	21.9%	23.3%
1992	68.1%	80.9%	65.0%	61.7%	5.6%	5.3%	19.1%
1993	67.0%	79.7%	62.0%	62.7%	0.5%	5.9%	20.1%
1994	69.4%	79.4%	60.0%	62.8%	4.3%	1.7%	22.9%
1995	65.9%	82.1%	58.0%	62.8%	-1.0%	7.7%	23.0%
1996	75.5%	78.6%	57.0%	63.8%	1.4%	11.7%	29.0%
1997	75.8%	76.5%	54.0%	63.9%	2.5%	-1.0%	34.3%
1998	75.5%	78.2%	52.0%	63.7%	-1.6%	4.7%	31.1%
1999	72.8%	75.7%	50.0%	63.9%	3.1%	-0.3%	26.2%
2000	69.5%	76.3%	50.0%	63.6%	1.6%	6.7%	25.2%
2001	67.7%	76.5%	50.0%	63.6%	0.8%	1.6%	27.5%
2002	66.1%	75.0%	47.0%	64.2%	0.9%	-0.9%	27.7%
2003	63.5%	77.8%	46.0%	65.1%	1.8%	4.9%	23.9%
Mean	69.5%	77.7%	64.3%	62.1%	0.5%	7.4%	20.0%

Notes: Labour share is the ratio of labour compensation to value added. Low skilled labour is the share of hours worked by employees without any formal educational qualification to total number of labour hours. Medium skilled labour is the share of hours worked by employees with a degree from secondary education to total number of labour hours. TFPG and RTFP are indices of TFP growth relative TFP from equations (8) and (7). Outliers have been excluded from the sample; the numbers of observations dropped is twenty-seven.

Econometric Models and Results

Benchmark Specification from Fixed Effects (FE) and Feasible Generalized Least Square Estimators (FGLS)

Following Bernard and Jones (1996a), the empirical convergence equation for Greece is an equilibrium correction model (ECM) represented by an ADL (1,1) process.[12] The level of productivity in industry *i* is co-integrated with productivity in the frontier country *GER* as follows:

$$\ln A_{i,GRC,t} = \beta_0 + \beta_1 \ln A_{i,GRC,t-1} + \beta_2 \ln A_{i,GER,t} + \beta_3 \ln A_{i,GER,t-1} + \omega_{i,GRC,t} \tag{9}$$

where ω stands for all the observed and unobserved effects that may influence $A_{i,GRC,t}$ (i.e. TFP in Greece- non-frontier country) and it is further decomposed as:

$$\omega_{i,GRC,t} = \sum_n \gamma_n Z_{i,GRC,t-1} + \rho_i + d_t + e_{i,GRC,t} \tag{10}$$

The summation in the right-hand side of (10) includes all the observed factors that have an impact on TFP such as R&D and trade while ρ and d control for industry and year specific effects. Assuming that the long-run homogeneity condition (i.e. $1-\beta_1 = \beta_2 + \beta_3$) holds in equation (9) then after transformation:

$$\ln \Delta A_{i,GRC,t} = \beta_0 + \beta_2 \ln \Delta A_{i,GER,t} + (1-\beta_1)(\ln A_{i,GER,t-1} - \ln A_{i,GRC,t-1}) + \omega_{i,GRC,t} \tag{11}$$

The substitution of (10) into (11) yields equation (12) in which the dependent variable is industry *i*'s TFP growth in Greece and the right hand-side, apart for trade and R&D, also includes the autonomous rate of industry *i*'s TFP growth in Germany and a term of technological gap in industry *i* between Germany and Greece. These augmentations lead to an estimatable equation of the following form:

$$\ln \Delta A_{i,GRC,t} = \rho_{i,GRC} + \alpha \ln \Delta A_{i,GER,t} + \gamma Z_{i,GRC,t-1} + \\ + \lambda \ln\left(\frac{A_{i,GER,t-1}}{A_{i,GRC,t-1}}\right) + \mu Z_{i,GRC,t-1} \ln\left(\frac{A_{i,GER,t-1}}{A_{i,GRC,t-1}}\right) + e_{i,GRC,t} \tag{12}$$

In (12), $\rho_{i,GRC}$ controls for industry individual heterogeneity, α captures the impact of TFP growth of German industries on the Greek counterparts, λ indicates the speed of technological transfer, Z includes other factors that have a direct effect on TFP growth such as: R&D, trade, labour market rigidities and market concentration. The estimate of μ measures the responsiveness of TFP growth with respect to changes in absorptive capacity. Intuitively, the interaction variable allows for industry heterogeneity in the productivity gap responses, which are mainly affected by the level of trade and R&D conducted in the industry. Note that the term TFP gap is the inverse of the relative TFP term presented in Table 1 and defined as: $\text{TFP gap} = \ln\left(\frac{A_{i,GER,t-1}}{A_{i,GRC,t-1}}\right)$.

[12] Further details about estimation issues of an ADL (1, 1) model can be found in Pesaran and Smith (1995).

Equation (12) is a fixed effects specification with the term $\rho_{i,GRC}$ to denote time-invariant industry dummies. This model can be estimated using a least squares dummy variable technique (LSDV), which is a standard OLS enriched with a set of dummy variables. Potentially, the use of the LSDV estimator can lead to biased results, as the industry fixed effects are likely to be correlated with the other covariates in the right hand-side. A Within-Group Fixed Effects (FE) estimator eliminates $\rho_{i,GRC}$ by expressing all variables as deviations from their sample means. According to Nickell (1981), the order of the bias emerged from the use of the FE estimator is of order $1/T$, where T is the number of years. Therefore, in panels with a relatively large number of time series the bias tends to zero. Evidence from Monte Carlo experiments (Judson and Owen, 1999) shows that if $T>N$, where N is the number of cross-sections then the FE estimator performs better than the instrumental variable (IV)-GMM estimator. In the current sample, after missing one year required for the construction of some variables, the panel consists of 23 years and 17 industries, which is a sufficient indication for the appropriateness of the FE within group estimator over the GMM.[13] As a further check of econometric robustness, we apply a dynamic panel data estimator of Anderson Hsiao (1982) to correct for potential bias of the order $1/T$.

Table 2 examines gradually the sources of productivity growth beginning with a fixed effects estimator (FE) estimator in columns (1) and (2). The first two columns report a set of standard specification tests concerning the behaviour of the error-term $e_{i,GRC,t}$. Firstly, the modified Wald test refers to whether the error term has a constant variance across industries, $Var(e_{i,t}) = \sigma_i^2$. Secondly, the Pesaran (2004) test provides information about the cross-sectional dependence of the residuals, $Cor(e_{i,t}e_{k,t}) \neq 0$ for any industry $i \neq k$. These tests indicate that heteroscedasticity and cross-sectional correlation are present in the current sample. Thirdly, the Wooldridge (2002) test examines the hypothesis of autocorrelation of the residuals, $Cor(e_{i,t}e_{i,t-1}) \neq 0$, the reported values suggest the acceptance of null at all the conventional levels of significance signifying the absence of first order serial correlation.

Specifications in columns (3)-(7) correct for group wise heteroscedasticity and cross-sectional correlation using the Feasible Generalized Least Squared (FGLS) estimator. The sources of productivity growth included in column (3) are the share of imports and exports with Germany, R&D share, their associated interaction terms and the minimum to median wage. Since our benchmark empirical model in (12) is derived from an equilibrium correction model (ECM), we augment specifications (3)-(7) with a contemporaneous term of TFP growth in Germany to allow for a more flexible relationship between non-frontier and frontier TFP. Results from the dynamic specification are presented in column (8).

[13] The estimation of a dynamic panel data model, as the one specified in (12), needs to address the correlation bias emerged between the lagged dependent variable and the fixed effects. Judson and Owen (1999) find that with a $T \approx 30$, a fixed effects estimator is the best alternative producing the smallest root mean square error (RMSE). The GMM estimator can more effectively correct the bias in panels with smaller number of years, $T<10$, while if $10<T<20$ then an Anderson Hsiao (1981) estimator should be chosen.

Table 2. Sources of TFP Growth, Estimates from Equation (12)

	(1)FE	(2)FE	(3)FGLS	(4)FGLS	(5)FGLS	(6)FGLS	(7)FGLS	(8)DP
TFP gap	0.05***	0.09***	0.06***	0.07***	0.08***	0.12	0.34***	0.10**
	[3.60]	[2.71]	[5.11]	[7.11]	[8.86]	[10.46]	[4.52]	[2.12]
$imp_{i,t-1}^{GER}$	-0.002	-0.10*	-0.04***				-0.04	-0.18***
	[0.29]	[1.87]	[3.46]				[0.85]	[2.68]
$imp_{i,t-2}^{GER}$				-0.011				
				[1.40]				
$imp_{i,t-3}^{GER}$					0.003			
					[0.65]			
$imp_{i,t-4}^{GER}$						-0.025***		
						[3.93]		
$exp_{i,t-1}^{GER}$	-0.01	0.00	0.00				-0.05*	0.02
	[1.37]	[0.23]	[0.71]				[1.74]	[0.33]
$exp_{i,t-2}^{GER}$				-0.007				
				[1.42]				
$exp_{i,t-3}^{GER}$					0.001			
					[0.36]			
$exp_{i,t-4}^{GER}$						0.031***		
						[6.12]		
$R\&D_{i,t-1}$	0.02***	0.06**	0.05***	0.02***	0.02***	0.02***	0.08***	0.04*
	[2.88]	[2.26]	[8.28]	[8.62]	[12.31]	[7.63]	[3.98]	[1.70]
Min/Med_{t-1}			-0.04	-0.02	-0.09	-0.09*	-1.38***	-0.046
			[0.68]	[0.51]	[2.08]	[1.71]	[4.29]	[0.71]
$\Delta A_{i,GER,t}$			0.03**	0.04**	0.06***	0.08***	0.01	0.04
			[2.00]	[2.46]	[3.91]	[3.40]	[1.51]	[0.71]
$CR_{i,t-1}$							-0.28***	
							[3.79]	
$imp_{i,t-1}^{GER} \times TFP\ gap$		0.03**	0.01***	0.00**	0.00*	0.00***	0.01	-0.05***
		[2.53]	[3.31]	[2.21]	[1.95]	[4.21]	[0.69]	[2.63]
$exp_{i,t-1}^{GER} \times TFP\ gap$		-0.00	0.00	0.00*	0.00***	0.00***	0.02	0.00
		[0.35]	[0.24]	[1.76]	[4.70]	[5.75]	[0.03]	[0.23]
$R\&D_{i,t-1} \times TFP\ gap$		-0.01*	-0.01***				-0.02***	-0.00
		[1.78]	[5.57]				[7.42]	[0.79]
$R\&D_{i,t-2} \times TFP\ gap$				-0.01***				
				[2.69]				
$R\&D_{i,t-3} \times TFP\ gap$					0.00			
					[0.29]			
$R\&D_{i,t-4} \times TFP\ gap$						0.03***		
						[5.97]		
Observations	389	389	368	352	336	320	160	352
R-squared	0.07	0.14						
Number of sectors	17	17	16	16	16	16	16	16
Modified Wald Test Chi2(17)	2360.93	2108.93						
	(0.00)	(0.00)						
Modified Wald Test Chi2(17)	2360.93	2108.93						
	(0.00)	(0.00)						
Cross Sectoral Dependence	8.918	8.974						
	(0.00)	(0.00)						
Wooldridge Test F(1,16)	0.083	2.399						
	(0.77)	(0.14)						

Notes: Absolute t-statistics in brackets correspond to *significance at 10%; ** significance at 5%; ***significance at 1%. All variables are expressed in logs. All specifications include industry fixed effects. The null hypothesis of the Modified Wald test is $H_0 : \sigma_i^2 = \sigma$. The cross-sectoral dependence test relies on the Pesaran test under the null $H_0 : E(e_{i,t} e_{k,t}) = \sigma_{i,k}$, where $i \neq k$ denote industries. The null hypothesis of the Wooldridge test is no serial correlation after allowing for an AR(1) process of the residuals. All the estimates reported from FGLS regression refer to the second stage results. The Dynamic Panel (DP) estimator in column (8) initialized by Anderson Hsiao (1982) estimator correcting for bias of the order (1/*T*). The estimate of the lagged dependent variable is 0.11.

Focusing our interpretation on the estimates of columns (3)-(7), the positive and statistically significant coefficient of TFP gap indicates that the further an industry lies behind the frontier, the faster is the rate of TFP growth. This variable captures the effect of autonomous technology transfer and the estimated coefficient is expected to be larger the longer is the distance from the frontier. The literature reveals different values of this coefficient signifying the different technological level of the non-frontier countries and their associated distance from the frontier. The relatively large value of the present coefficient, within the interval 5%-34%, suggests a substantial technological falling behind for Greece resulting in a large degree of potential for technology transfer. On the contrary, the coefficient of autonomous technology transfer lies within 3.6-7.3% between Japan and USA (Cameron (2005)) and within 6.4%-6.7% between France and the US (Khan (2006)). The low speed of adjustment in the above studies indicates that the follower countries have almost exhausted technology transfer hence other policy instruments should be explored to stimulate productivity growth.

In column (3), the estimates of trade variables initially suggest an ambiguous pattern. The estimated coefficient of import share has a negative and statistically significant coefficient, while the associated interaction term with TFP gap suggests that raising the share of imports from Germany accelerates the pace of technology transfer. A similar effect is revealed for the interacted term of export share with TFP gap. To check whether the negative pattern of import share persists, we allow for hysteresis in the exploitation of trade-induced learning effects using higher order lags of import and export shares. We consider up to four lags and the estimates are shown in columns (4)-(6).The negative coefficient of import share is retaining for all four lags. Nonetheless, the estimated coefficient of the fourth lag of export share is positive and statistically significant revealing export learning gains for Greek manufacturing industries whose implementation requires substantial time lag.[14] On the contrary, the role of imports and exports is evident on accelerating the speed of technology transfer throughout the whole range of specifications.

The coefficient of R&D share is positive and statistically significant almost at the 1% percent level in all specifications of Table 2. Nonetheless, the estimated coefficient - also known as the social return to R&D- is within the interval 2%-6.6%, which is far lower than the interval found in some benchmark studies of the literature.[15] However, the coefficient of the one-year lag interaction term of R&D with TFP gap in column (3) is negative. We test for the existence of hysteresis applying lags of order t-2, t-3 and t-4. A positive and statistically significant estimate is only revealed with the use of the fourth order lag confirming that the R&D-based absorptive capacity impacts on TFP growth with severe time delay.[16] As expected, the coefficient of contemporaneous TFP growth is always positive. For instance, one can interpret the estimated parameter in column (3) as a 1% TFP growth increase in the German industry raises TFP growth in the Greek counterpart by 3.8%. Turning to findings from the dynamic panel estimator in column (8), estimates are relatively weaker as the significant effect from other productivity sources is now captured from

---

[14] Although we do not present the results here, we have also experimented with the fifth order lag of exports, which is positive and statistically significant at the one percent level.

[15] Griliches and Lichtenberg (1984) and Scherer (1982, 1984) find a social return to R&D between 21-76% and 29-43%, respectively.

[16] The absorptive capacity gains are implemented with hysteresis but they are also relatively weaker compared to the estimate of 8% found in Kneller (2005) for a sample of non-frontier OECD countries.

the lagged dependent variable. Interestingly, technology transfer and domestic R&D activity remain the most important engines of TFP growth. The coefficients of the other variables remain qualitatively similar to those obtained from FGLS. Combining the evidence obtained from dynamic panel and FGLS regressions, we can safely argue that our results, apart from few minor differences, are not driven from specification bias.

The coefficient of the minimum to median wage allows us to assess whether a regulated market through a minimum wage setting increases labour cost adjustments far above the market-clearing levels hampering the rate of TFP growth. On that basis, the negatively signed estimates in Table 2 tend to support the notion that powerful trade unions slow down productivity growth. The implementation of the welfare program in 1980s might have also led to a critical trade off as it increased labour cost adjustments through the allocation of the resources away from productive activities into employment benefits. The fact that Greece and France experience the higher minimum to median ratio in a group of OECD countries along with the negative coefficient of minimum to median wage also found in Khan (2006) suggest that the negative link between labour protective policies and productivity tends to be systematic.

Column (7) introduces domestic market concentration as a determinant of productivity growth.[17] Note the specification in column (7) refers to a reduced sample of eleven years, as data for CR are only available from 1993 onwards. The pattern revealed confirms that the greater the concentration ratio of the market the lower the rate of TFP growth. Interestingly, the quantitative effect of this estimate is rather robust suggesting that a 1% increase in the degree of concentration decreases the rate of TFP growth by almost 28%. The literature of the productivity-concentration nexus already highlights many controversies. Our result supports the findings of Vickers (1995) and Nickell (1996) who consider market concentration as a cause of slack. Nonetheless, the reader may treat the consistency of our result with other empirical findings with some caution, as there is no one-to-one correspondence as far as the analytical framework is concerned between our study and the studies mentioned above. For instance, while most of the above papers have a quite similar definition of market concentration to the one used here, their focus is on productivity levels rather than on productivity growth rates.

Instrumental Variable (IV) Estimation and Further Tests of Robustness

The formulation of equation (12) indicates that shocks in the TFP level of Greece at year t-1 affect both TFP growth and the initial distance from the frontier. This realization enhances an endogeneity problem between TFP growth and TFP gap. Similarly, endogeneity might exist between TFP growth and trade. The neoclassical trade theory identifies as a source of comparative advantage the different level of productivity across countries, accordingly productivity is the determinant of trade and not vice versa. To control for endogeneity problems as well as to correct for any potential measurement bias already embodied in the measure of TFP, an IV (instrumental variable) estimator is applied. The criterion for choosing the correct instruments is to be associated with the endogenous variables and be uncorrelated with the error term of the TFP growth equation (12). In view of the fact that the

[17] The computation of this variable is demonstrated in Appendix B.

residual term is serially uncorrelated, based on the reported Wooldridge test in Table 2, suitable instruments can be higher order lags of the endogenous variables.

The last two rows of Table 3 report some identification tests regarding the validity of instruments. The canonical LM test refers to whether the equation is correctly identified or equivalently that the excluded instruments are relevant. The null hypothesis of this test assumes that the equation is under-identified and the associated statistic follows the Chi-squared distribution with degrees of freedom (L, K+1), where L is the number of instruments and K is the number of endogenous regressors. Alternatively, the Sargan test refers to the hypothesis that the instruments are uncorrelated with the residual term. Under the null hypothesis, the Sargan statistic follows the Chi-squared distribution with (L-K) degrees of freedom. According to the reported values, the canonical test rejects the null of an under-identified specification while the Sargan test does not reject the null of no correlation of instruments with the error term. Overall, these statistics indicate that our set of instruments is valid.

The IV estimates of Table 3 are now relatively weaker from a statistical point of view. In brief, the most considerable difference between IV and FGLS estimations is that there is no evidence for R&D based absorptive capacity even after allowing for hysteresis. Autonomous technology transfer appears to be the only statistically significant coefficient. Innovation rate as reflected through R&D is statistically significant at the 10% level and this only after considering third order lags in trade variables. As before, the third order lag of export share reveals productivity gains, but this coefficient is only of minor statistical significance. Finally, the coefficient of the minimum to median wage is statistically insignificant even if it maintains a negative sign. The less robust results from the IV estimation are an expected trade-off resulted in from controlling for unobserved measurement errors and endogeneity bias.

Further Tests of Robustness

Furthermore, we experiment with alternative definitions of key variables focusing mainly on two objectives, first to investigate the sensitivity of the results presented in Table 2 using a stock measure of R&D and, second to analyse more systematically whether the pattern of trade impacts on TFP growth. The calculation method of R&D stock is shown in (13) where the second part describes the formula used to initialize the series with g and δ to denote the rates of growth of R&D investment and depreciation:

$$R\&D_{i,t}^{Stock} = (1-\delta)R\&D_{i,t-1}^{Stock} + R\&D_{i,t-1}^{Investment}$$
$$R\&D_{i,t=1980}^{Stock} = \frac{R\&D_{i,t=1980}^{Investment}}{\frac{1}{n}g_i^{R\&D} + \delta}, \quad \delta=15\% \qquad (13)$$

Learning-by-trading shares many similarities with learning-by-doing as rigorously analyzed by Arrow (1962). The analogies of Arrow's analysis in a trade context imply that learning-by-trading might be subject to diminishing returns and thus trade-induced gains are non-infinite but exist only up to a certain threshold beyond which, an increase of trade involvement is not anymore beneficial.[18] Young

[18] This crucial threshold determines only the existence of learning gains that derive from the repetition of the same activity. Exceeding this threshold does not have further implications on

(1991) and Chaung (1998) formalize this scenario emphasizing a bounded type of trade-induced learning, which can be empirically implemented with controlling for a non-linear relationship between trade and TFP growth.

We obtain statistically significant coefficients for R&D stock (column (4), Table 3) but the size of this coefficient tends to be smaller than the coefficient of the R&D flow (Table 2). Column (4) of Table 3 replicates specification 3 of Table 2 using the quadratic terms of trade and the third lag of the interaction term of R&D stock with TFP gap. The only noticeable difference is that the quadratic term of exports is positive, revealing a U-shaped relationship between export gains and TFP growth.

Finally, column (3) tests the well–established positive link between human capital and productivity often found in country level studies (Black and Lynch (2001)). The main hypothesis tested is whether a higher educational level on average leads to a higher productivity growth. The measure of human capital is defined as the share of workers with a University degree. The estimates shown in column (5) tend to support the positive role of human capital on productivity growth without affecting absorptive capacity.

---

the welfare gains of trade that are always present highlighting the static positive effects upon consumer surplus.

Table 3. Sources of TFP Growth, IV Estimation and Further Specifications of Equation (12)

VARIABLES	(1)2SLS	(2)2SLS	(3)2SLS	(4) FGLS	(5)FGLS
TFP gap	0.22**	0.13	-0.12	0.09**	0.05
	[2.17]	[0.73]	[0.34]	[8.39]	[1.36]
$imp_{i,t-1}^{GER}$	-0.202*				
	[1.75]				
$imp_{i,t-2}^{GER}$		-0.01			
		[0.10]			
$imp_{i,t-3}^{GER}$			-0.04		0.02
			[0.40]		[0.26]
$exp_{i,t-1}^{GER}$	0.02				
	[0.56]				
$exp_{i,t-2}^{GER}$		0.01			
		[0.37]			
$exp_{i,t-3}^{GER}$			0.11*		0.00
			[1.83]		[0.28]
$imp \times imp_{i,t-1}^{GER}$				-0.00***	
				[5.37]	
$exp \times exp_{i,t-1}^{GER}$				0.00***	
				[8.16]	
$R\&D_{i,t-1}$	0.07	0.02	0.04*		
	[1.08]	[1.30]	[1.79]		
$R\&D\ stock_{i,t-1}$				0.01***	0.01***
				[6.21]	[4.65]
$HC_{i,t}$					0.082*
					[1.90]
Min/Med_{t-1}	-0.53	-0.35	0.83	-0.25***	-0.026
	[1.41]	[0.51]	[0.62]	[5.75]	[0.19]
$\Delta A_{i,GER,t}$	-0.09	0.08	0.05	0.04***	0.06***
	[1.35]	[1.03]	[0.64]	[3.19]	[3.28]
Interaction Terms					
$imp_{i,t-1}^{GER} \times TFP\ gap$	0.05*	0.00	-0.00	-0.03**	0.03
	[1.84]	[0.21]	[0.06]	[2.49]	[1.57]
$exp_{i,t-1}^{GER} \times TFP\ gap$	-0.00	0.00	0.00	0.01***	0.06***
	[0.34]	[0.85]	[0.06]	[8.25]	[5.24]
$R\&D_{i,t-1} \times TFP\ gap$	-0.02				
	[0.66]				
$R\&D_{i,t-2} \times TFP\ gap$		0.00			
		[0.42]			
$R\&D_{i,t-3} \times TFP\ gap$			-0.00		
			[0.09]		
$R\&D\ stock_{i,t-3} \times TFP\ gap$				0.00	-0.00
				[1.05]	[0.39]
$HC_{i,t-1} \times TFP\ gap$					-0.026
					[1.52]
Diagnostic Tests					
Observations	336	320	288	336	336
R-squared	0.10	0.17	0.024		
Number of sectors	16	16	16	16	16
Industry Fixed Effects	Yes	Yes	Yes		
Wald Test Chi2(24)				366.13	279.86
				(0.00)	(0.00)
Canonical LM Test	76.98	24.64	7.40		
	(0.00)	(0.00)	(0.01)		
Sargan Test	6.22	31.43	7.72		
	(0.39)	(0.13)	(0.25)		

Notes: For asterisks correspondence see Table 2. The endogenous regressors are *TFP gap*, $\log(imp)^{GER}_{i,t-1}$, $\log(exp)^{GER}_{i,t-1}$, $\log(imp)^{GER}_{i,t-1} \times TFP\ gap$, $\log(exp)^{GER}_{i,t-1} \times TFP\ gap$ and $\log(R\,\&\,D)_{i,t-1} \times TFP\ gap$. The set of instruments in columns (1)-(3) are the lagged values of the endogenous variables at years t-2, t-3. In IV estimations, the reported R-squared is observed from the first-stage regression. The null hypothesis of the canonical LM test is that the equation is under-identified. The null hypothesis of the Sargan test is that the instruments are valid (uncorrelated with the error term). Wald test refers to the hypothesis that estimated parameters are jointly statistically equal to zero and follows the chi-squared distribution. Figures below the diagnostic test represent p-values.

Discussion and Concluding Remarks

This paper investigates the determinants of productivity growth with special emphasis to technology transfer. Technological diffusion across countries gains much attention in the present framework since faster adoption of technology, which is already available somewhere else, leads to productivity convergence. Productivity convergence remains a topical issue in the agenda of European economic integration as guarantees the harmonization of key performance characteristics between peripheral and core countries of the EU.

Results from both benchmark and further specifications suggest that autonomous technological transfer is important for the movements of TFP growth. Nonetheless, the speed of autonomous technology transfer is very slow, certainly lower than other findings documented in the literature. The low speed of autonomous technological convergence explains to a large degree why there still exists a high technological gap between Greece and Germany at the end of the period. Excluding column 7 in Table 2, the average value of the coefficients reported is 0.086. From the steady state condition in equation (5),[19] one can derive that a typical Greek manufacturing industry needs about 40 years to close half the gap in technical efficiency that separates it from the German counterpart.

A possible explanation for Greece's permanent difficulty to exploit Germany's technological advance is that Greece's business environment is characterized by many chronic rigidities that reflect both industry-specific structures and broader institutional aspects. At the industry level, anachronistic organisational schemes decelerate the adoption of foreign technology (Prescott, 1997) while the lack of central planning for the implementation of appropriate institutional reforms, maintains bureaucratic practices that are serious impediments to a quick adoption of foreign technology. The fact that the current empirical evidence shows that Greece makes little benefit from Germany's technological leadership should not be viewed as evidence against the importance of international technology transfer. The current exercise focuses only on a pair of countries with strong bilateral trade relationships but does not exhaust the potential sources of productivity growth. Adding more trading partners in the current set up might prove more effective in revealing knowledge gains for the Greek manufacturing sector. Future analysis can also account for sources that are unexplored in this paper such as FDI and physical proximity to international markets.

Apart from the low speed of autonomous technology transfer, the empirical analysis highlights three main findings. First, the implementation of trade gains occurs with a time lag of three years. The pattern revealed also suggests the bounded nature of learning-by-exporting gains. In any case, the positive estimates of the

[19] The reader can find in Appendix C the calculation for the time needed to cover half gap of technical efficiency at steady state. There is also unit root test for stationarity testing whether equation (9) is correctly specified as an equilibrium correction model (ECM).

interaction trade terms indicate that trade is an important engine of growth by accelerating the adoption of technology from the frontier to the laggard country.

Second, the effect of R&D on TFP growth is relatively smaller than in other studies but higher rates of innovation are always associated with higher rates of TFP growth. This result is insensitive to alternative measures of R&D and econometric specifications.

Third, the variables included reflecting institutional factors, minimum to median wage, and market concentration are consistently negative. The analysis confirms the existence of a negative effect of powerful trade unions on economic performance while the existence of dominant firms in the market causes slack that leads to an industry productivity slowdown.

From a policy-making standpoint, the variable of labour market rigidities can provide interesting insights that must be treated cautiously as this variable is only a proxy. There are various alternative measures to reflect more accurately the power of trade unions such as the number of missing working hours due to strikes but this data series is unavailable at the industry level. For Greece, the intensive implementation of a welfare state program in 1980s was necessary for bridging the gap of income inequalities but this made the labour market even more rigid adding to the already distorted business environment. However, we are far from saying that less state intervention in labour markets will definitely benefit TFP; instead, a central planning seems necessary for transforming the economy towards more dynamic activities that embody substantial knowledge spillovers that may benefit overall productivity.

Acknowledgements

I would like to thank Roger Vickerman, Maria-Garcia Alonso, Rod Falvey, Hans Martin Krozlig and two anonymous references for useful comments and advice in an earlier draft of the paper. I have been also benefited from useful feedback by participants of the 3rd PhD Symposium of the Hellenic Observatory at LSE and the 9th Conference of the European Trade Study Group (ETSG). I am also grateful to David Kernohan and Michela Vecchi for useful suggestions and comments in the latest version of the paper.

References

Abramovitz, M. 1986. Catching up, Forging Ahead, and Falling Behind. *Journal of Economic History* 46: 385-406.

Acemoglu, D., and F. Zillibotti. 2001. Productivity Differences, *Quarterly Journal of Economics*, 16: 563-606.

Anagnostaki, V., and H. Louri. 1995. Entry and exit from Greek manufacturing industry: a test of the symmetry hypothesis, *International Review of Applied Economics* 9:86-95.

Anderson, W., and C. Hsiao. 1982. Formulation and Estimations of Dynamic Models Using Panel data, *Journal of Econometrics* 18: 47-82.

Arrow, K. 1962. The Economic Implications of Learning by Doing, *Review of Economic Studies*29:155-173.

Bernard, A., and C. Jones. 1996a. Productivity across Industries and Countries: Time Series Theory and Evidence, *Review of Economic and Statistics* 78: 135-146

Bernard, A., and C. Jones. 1996b. Comparing Apples to Oranges: Productivity Convergence and Measurement across Industries and Countries, *American Economic Review* 86: 1216-1238.

Bernard, A., and S. Durlauf. 1995. Interpreting Tests of the Convergence Hypothesis, *Journal of Econometrics* 71: 161-173.

Bernard, A. and B. Jensen. 1999a. Exceptional Exporter Performance: Cause, Effect, or Both? *Journal of International Economics* 47: 1-25.

Bernard, A., and B. Jensen. 1999b. Exporting and Productivity, *NBER* Working Paper No 7135.

Black.S., and L. Lynch. 2001. How to Compete: The Impact of Workplace Practices and Information Technology on Productivity. *Review of Economic and Statistics* 83*:* 434-445.

Cameron, G. 2005. The Sun Also Rises: Productivity Convergence between Japan and the USA. *Journal of Economic Growth* 10: 387-408.

Cameron, G. 2006. Openness, R&D, and Growth at the Industry Level, *Perspectives in Economic Growth*. Edited by L.A. Finley. Chapter5: 137-158.

Castellani, D. 2002. Export Behaviour and Productivity Growth: Evidence from Italian Manufacturing Firms. *Review of World Economics* 138: 605-628.

Caves, D., L. Christensen, and E. Diewert. 1982. Multilateral Comparison of Output, Input and Productivity using Superlative Index Numbers. *Economic Journal* 92: 73-86.

Caves, R. 1987. *Britain's Productivity Gap*. Cambridge: Cambridge University Press

Clerides, S., S.Lach, and J.Tybout. 1998. Is Learning by Exporting Important? Micro-dynamic Evidence from Colombia, Mexico and Morocco. *Quarterly Journal of Economics* 113: 903-947.

Coe, D., and Helpman, E. 1995. International R&D Spillovers, *European Economic Review* 39: 859-887.

Cohen, W., and D. Levinthal. 1989. Innovation and Learning: The Two faces of R&D. *Economic Journal* 99: 569-596.

Fotopoulos, G. and N. Spence. 1997. Net Entry of Firms into Greek Manufacturing: The Effects of Business Conditions. *Small Business Economics* 9:293-253.

Griffith, R., S.Redding, and J. V. Reenen. 2003. R&D and Absorptive Capacity: Theory and Empirical Evidence. *Scandinavian Journal of Economics* 105: 99-118.

Griffith, R., S. Redding, and J.V.Reenen. 2004. Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Countries. *Review of Economics and Statistics* 86: 883-895.

Griliches, Z. 1980. Returns to R&D Expenditures in the Private Sector in Kendrick, Edited by K., Vaccara, *Development in Productivity Measurement*. Chicago: Chicago University Press.

Griliches, Z., and F. Lichtenberg. 1984. R&D Productivity at the Industry Level: Is there still a Relationship. Edited by Z. Griliches, *R&D, Patents and Productivity*. Chicago: Chicago University Press.

Grossman, G., and E. Helpman. 1991. Innovation and Growth in the Global Economy. Cambridge: MIT Press.

Hall, R. 1990. Invariance Properties of Solow's Productivity Residual. Edited by P. Diamond, *Growth Productivity Unemployment*. Cambridge: MIT Press.

ICAP 1993-2003. Greek Financial Directory: *Greece in Figures.*

Jovanovic, B. 1982. Selection and Evolution of Industry. *Econometrica*, 50:649-670

Judson, A., and L. Owen. 1999. Estimating Dynamic Panel Data Models: A guide for Macroeconomists. *Economics Letters* 65: 9-15.

Keller, W. 1998. Are International R&D Spillovers Trade-Related?. Analyzing Spillovers Among Randomly Matched Trade Partners. *European Economic Review* 42: 1469-1481.

Khan, T. 2006. Productivity Growth, Technological Convergence, R&D, Trade, and Labour Markets: Evidence from the French Manufacturing Sector. *IMF* Working paper No 230.

Kneller, R. 2005. Frontier Technology, Absorptive Capacity and Distance. *Oxford Bulletin of Economics and Statistics* 67: 1-23.

Kraay, A. 1999. Exportations et Performances Economiques: Etude d' um Panel d' Enterprises Chinoises. *Revue d' Economie du Dėveloppement*, 1-2/1999, 183-207.

Kwiatkowski, D., P.Phillips, P.Schmidt, and Y.Shin. 1992. Testing the Null Hypothesis of Stationarity Against the Alternative of a Unit Root: How Sure Are We That Economic Time Series Have a Unit Root?. *Journal of Econometrics* 54: 159-178.

Nickell, S. 1981. Biases in dynamic models with fixed effects. *Econometrica* 49: 1417–1426.

Nickell, S. 1996. Competition and Corporate Performance. *Journal of Political Economy* 104: 724-746.

O' Mahony, M. 1996. Conversion Factors in Relative Productivity Calculations: Theory and Practice, *OECD* Working Papers.

Pesaran, H., and R, Smith. 1995. Estimating Long –Run Relationships from Dynamic Panels. *Journal of Econometrics* 68: 79-113.

Prescott, E. 1997. Needed: A Theory of Total Factor Productivity *Federal Reserve Bank of Minneapolis*. Research Department Staff Report 242.

Parente, S., and E. Prescott. 1994. Technology Adoption and Growth. *NBER* Working Paper No.3733.

Redding S., G. Cameron, and J. Proudman. 2005. Technological Convergence, R&D Trade and Productivity Growth. *European Economic Review* 49: 775-807.

Scherer, F. 1982. Inter-industry Technology Flows and Productivity Growth. *Review of Economics and Statistics* 64: 627-634.

Scherer, F. 1984. Using linked Patent and R&D Data to Measure Inter-industry Technology Flows. Edited by Z. Griliches, R&D, Patents and Productivity. Chicago: NBER and University of Chicago Press.

Schmalensee, R. 1977. Using the H-Index of concentration with published data. *Review of Economics and Statistics* 59: 186–193.

Schwert, W. 1989. Tests for unit roots: A Monte Carlo investigation. *Journal of Business and Economic Statistics* 7: 147-160.

Siebert, H. 1997. Labor Market Rigidities: At the Root of Unemployment in Europe. *Journal of Economic Perspectives* 11:37-54.

Solow, R. 1957. Technical Change and the Aggregate Production Function. *Review of Economics and Statistics* 39: 312-320.

Spence, M. 1984. Cost Reduction, Competition, and Industry Performance. *Econometrica* 52: 101-122.

Vickers, J. 1995. Concepts of Competition. *Oxford Economic Papers* 47: 1-23.

Wooldridge, J. 2002. Econometric Analysis of Cross-Sections and Panel Data. MIT: MIT Press.

Young, A. 1991. Learning by Doing and the Dynamic Effects of International Trade. *The Quarterly Journal of Economics* 106: 369-405.

Young, A. 1995. The tyranny of the Numbers: Confronting the Statistical Realities of the East Asian Growth Experience. *The Quarterly Journal of Economics* 110: 641-680.

Appendix A

The selection of Germany as a frontier economy is based on two criteria: (i) the productivity leadership of Germany that stimulates Greece's potential for faster technological catching up and (ii) the strong trade relations between the two countries. The Table below shows that relative labour productivity is always lower than unity while anecdotal evidence confirms the Germany productivity leadership in EU. Greece's imports from Germany account for 16.65% of total imports while 13% of Greece's exports are shipped to Germany.

Greece- Germany Bilateral Trade and Relative Labour Productivity, 1980-2003

Manufacturing Industries	Industry Code	Share of Greek Exports to Germany	Share of Greek Imports from Germany	$\left(\frac{VA}{H}\right)_{GRC} \Big/ \left(\frac{VA}{H}\right)_{GER}$
Food , beverages and tobacco	15t16	15.5%	16.0%	25.0%
Textiles, textile , leather and footwear	17t19	41.2%	19.2%	26.0%
Wood and products of wood and cork	20	7.4%	6.1%	18.0%
Pulp, paper, paper , printing and publishing	21t22	6.0%	17.3%	20.0%
Coke, refined petroleum and nuclear fuel	23	0.3%	3.4%	25.0%
Chemicals and chemical products	24	8.4%	18.8%	19.0%
Rubber and plastics	25	11.4%	19.4%	17.0%
Other non-metallic mineral	26	4.5%	10.8%	25.0%
Basic metals	27	10.5%	9.1%	35.0%
Fabricated metal	28	11.1%	20.6%	12.0%
Machinery	29	11.9%	23.2%	18.0%
Electrical machinery and apparatus	31	16.5%	24.2%	31.0%
Radio and television receivers	323	36.4%	23.7%	78.0%
Medical, precision and optical instruments	33	12.1%	20.8%	17.0%
Motor vehicles, trailers and semi-trailers	34	5.2%	30.8%	16.0%
Other transport equipment	35	11.1%	6.0%	32.0%
Other Manufacturing	36t37	12.0%	13.8%	32.0%
Average		13.0%	16.7%	26.0%

Appendix B

Data Sources and Definition of Variables

Total Factor Productivity (TFP)

TFP is calculated from EUKLEMS database. We also obtain data some information from OECD.

Output variables:

- Gross value added at current basic prices in millions of Euros (VA), Gross value added price indices Volume, 1995=100 (VA_P),

Input Variables:

- High-skilled labour compensation as a share of total compensation (LABHS),
- Medium-skilled labour compensation as a share of total compensation (LABMS)
- Low-skilled labour compensation as a share of total compensation (LABLS).
- Hours worked by high-skilled persons engaged (H_HS)
- Hours worked by medium-skilled persons engaged (M_HS)
- Hours worked by low-skilled persons engaged (L_MS)
- Capital compensation in millions of Euros (CAP)
- Fixed Capital formation deflators (OECD-Economic Outlook)
- Capacity utilisation(OECD-Main economic Indicators)
- **Common Currency Conversion**:
- PPP Exchange rate-National currency per international USD (WBDI-International Comparison Project)

Trade

Import and export shares are defined as the shares of imports (exports) to total output. Data for the calculation of trade variables are taken from OECD-STAN (releases 01 and 05). Due to lack of appropriate deflators, trade variables are expressed in nominal values.

Research and Development

R&D share is defined as the ratio of R&D expenditure to value added. Data for R&D expenditure are taken from OECD in current PPP-USD (Main Science and Technology Indicators, releases: 13r2-13r3). The series starts from 1981 and missing values are filled in with an interpolation routine. We deflate nominal R&D values with an R&D price index defined as: $PR = 0.5(VA\_P + WAI)$, where VA_P is a value added industry specific deflator and WAI is a nominal manufacturing wage index, taken from the International labour Organization (ILO). The appropriateness of this R&D deflator is justified by the notion that half of the R&D expenditures refer to labour costs (Coe and Helpman (1995)).

Human Capital

Human capital is defined as the share of hours worked by workers with at least a University degree. Data are obtained from EUKLEMS.

Concentration Ratio

We follow Schmalensee (1977) measuring concentration index as follows:

$$CR = \frac{(AS_1 - AS_2)^2 (n_1^2 - 1)}{3n_1} + h \quad ; \quad h = n_1 (AS_1)^2 + (n - n_1)(AS_2)^2$$

where AS_1 and AS_2 are the average market shares of the five largest firms and the remaining firms of the industry, respectively. Using n and n_1 to denote the total firm population and the group of the largest firms in the industry (i.e. in the current case this is five), the above index is easily computable. According to Schmalensee (1977), the current index is the second best alternative after Herfindahl-Hirschman index. The market share of the top five firms in each industry is calculated by total assets in nominal values as provided by ICAP. The latter data set is only available for 1993 to 2003.

Appendix C

Relative TFP at Steady State

An empirical representation of equation (5) is $\ln\left(\frac{A^*_{i,GRC}}{A^*_{i,GER}}\right) = \frac{\gamma_{i,GRC} - \gamma_{i,GER}}{\bar{\lambda}_{i,GRC}} = \frac{0.0735 - 0.0045}{0.081}$, which provide us with the value of RTFP between Greece and Germany in steady state. To calculate the speed of adjustment in autonomous technology transfer, we consider as $\gamma_{i,GRC}$ and $\gamma_{i,GER}$, the average growth rates of TFP over the whole period under study. The speed of technology transfer is determined by the parameter $\bar{\lambda}_{i,GRC}$, which is the average value of all TFP gap coefficients reported in Table 2 (i.e. the estimate of column (7) is ignored due to the reduced sample). The above calculations indicate that RTFP in steady state is 85%.

A formal Test of Convergence

We follow Bernard and Durlauf (1995) and Bernard and Jones (1996a) to obtain a formal test of convergence for each industry. In the present framework a Greek industry *i* is said to converge towards its German counterpart *i* if TFP gap is stationary. We implement a stationarity test developed by Kwiatkowski et al.(1992) or KPSS, which differs from the standard Dickey-Fuller and Perron unit root tests by directly specifying a null hypothesis of stationarity. As shown in the table below, the null hypothesis of stationarity is not rejected in all industries, which connotes that equation (9) is a close approximation of an ECM.

Unit Root Tests

Industry Code	15t16	17t19	20	21t22	23	24	25	26	27	28	29	31	323	33	34	35
Trend	0.15	0.16	0.15	0.14	0.14	0.15	0.15	0.14	0.15	0.14	0.15	0.16	0.15	0.14	0.2	0.16
Level	0.39	0.39	0.39	0.4	0.39	0.39	0.39	0.42	0.4	0.38	0.37	0.39	0.4	0.15	0.4	0.4

Notes: The null Hypothesis in both columns is that TFP gap is stationary or equivalently that each industry converges. Critical Values are taken by KPSS (1992) for trend stationarity are: 2.5%:0.176;1%:0.216. Critical Values for Level stationarity are: 2.5%:0.574; 1%:0.739. The number of the lags considered is 8 as indicated by the Schwert (1989) rule.