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

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1. Introduction

Special attention has been given in the field of development economics to understanding the sources of economic growth. Solow (1957)[2], who was the first initiates the concept of the residual in a standard production function provides the most influential study in the theory of economic growth. In the Solow approach, the real sources of technical change over time are considered to be disembodied to production inputs, implying that technological improvement over time is not included in the inputs of labour and capital. Because of this feature of the Solow model, the real sources of technical change are considered to be exogenous.[3] The "new" growth theory relaxes a crucial assumption of the neoclassical theory regarding the diminishing returns to capital[4] suggesting that the determinants of growth are endogenous rather than exogenous. In the endogenous growth theory, technical change – the parameter *A* in the Solow aggregate production function- is not anymore a measure of our ignorance; instead, it is embodied in the factors of production and it is subject to an interplay between the structure of the economic system and the production process. From this respect, technical improvements can be enhanced within an increased variety of capital goods or within a higher level of human capital and certainly these factors cannot be considered (Aghion and Howitt (1998)) as independent from factors of production. In the same line of argument, classical ideas of learning by

[2] It should be mentioned that Solow (1957) was not the first one that tries to tie an aggregate production function; this attempt is also documented in Tinbergen (1942). However, Solow was the first that links the idea of growth with the estimation of an efficiency parameter.

[3] The initial formulation of the Solow model is $Q_t = A_t F(K_t, L_t)$, where *A* is a Hicks- neutral technical parameter. Any shift of this parameter over time is "costless"- this highlights the feature of a disembodied technical change- and can increase output. This is why parameter A is referred to as the "Manna of Heaven". In a more realistic setting, the above formulation gives the opportunity of an econometric estimation regarding the contribution of the otter factors in shifting technical change over time. Hulten (2000) provides a short biography about the formulation and various considerations exist in the literature regarding the modeling of parameter A in the Solow model.

[4] The neoclassical theory assumes that capital is subject to diminishing returns and given the assumption of identical preferences and technology across countries then poor countries tends to grow faster relative to rich ones. Baumol (1986) fails to document this prediction of convergence emerges in the neoclassical theory. This failure is that gives a strong inspiration on the development of the endogenous growth theory. Under the assumption of diminishing or constant returns, an assumption of convergence toward to long run steady state equilibrium at the natural rate cannot be made. This finding implies that investment is important for growth and thus it can be viewed as endogenous (Thirwall (2003)). Investment can be associated as mentioned above with a bigger variety of capital goods and thus more technologically advanced and it can be linked to a more general definition of capital like human capital. The pioneer endogenous growth model are developed by Lucas (1988) and Romer (1986,1990).

doing can be accommodated in the endogenous theory reflecting the fact that the accumulation of knowledge can be a plausible source of economic growth.

One should not view these two theories as being contradictory to each other, instead the new growth theory is a complementary framework of the traditional growth accounting providing a more insightful and systematic analysis about the sources of economic growth across nations. Along with accumulation of physical and human capital, some new concepts have been added to the agenda of economic growth, with the most prominent being those of innovation and trade. The theoretical argument is that each of these two activities enhance a significant amount of positive knowledge externalities that can act as promoters of economic growth. Nevertheless, empirical literature does not always support the positive influence of these variables on growth - at least in the case of trade (Romer and Frankel (1999)). This empirical ambiguity stimulates further research not regarding whether innovation causes trade but in determining the precise mechanisms through which trade and innovation can meaningfully affect the rates of economic growth.

The present study contributes to the literature of economic growth, investigating the determinants of growth of total factor productivity (henceforth TFP) in Greek manufacturing industries. The investigation implemented within a concept of convergence between a non-frontier country, which is Greece and a frontier, which is Germany. As it stands convergence represents the potential of technology transfer between countries with different levels of productivity. Technology transfer is measured by an industry's relative index of TFP between Greece and Germany. The present concept of convergence is not identical to the classical idea of β and σ convergence met in the cross-country growth literature (Barro and Sala-i-Martin (1995)). The difference is that β convergence, for example, is concerned with the relationship between a country's growth rate and its initial per capita income, while in the present study convergence refers to industry's TFP growth and its initial distance from the frontier. Similarly, σ convergence analyses the evolution of a growth measure of cross-section dispersion while here the focus is on the time-series relationship between TFP in the non-frontier and the frontier economy[5].

The analysis of convergence from this different angle is an up-to-date theme in the productivity growth agenda and based on a model initially developed by Bernard and Jones (1996a, 1996b) and it has been adopted for a more informative measure of TFP by Redding et al. (2005). Apart from these studies, further evidence for the empirical validity of this convergence model is pretty rare. Exceptions are a studies from Griffith et al.(2004), Cameron (2005) and Khan (2006) that test the model for a group of OECD countries, for Japanese and US industries and for French and US industries, respectively.

Despite the poor number of studies that analyse TFP convergence, the latter issue is of special interest from a policy-making point of view, especially for the ongoing process of European economic integration. A number of structural changes have taken place in the European Union within the last fifteen years, such as trade barriers removal, a common currency Union, formulation of a common economic policy for a number of issues, have as final objective a successful and sustainable economic integration across European member states. A relatively more integrated Europe without this type of constraints minimizes transaction costs, risks and uncertainties giving the opportunity to less developed economies to converge in a more rapid pace towards the economic level of more developed EU economies.

The present study has three main goals. Firstly it seeks to enrich the literature of TFP convergence using a lengthy panel from 1980-2003 quantifying the speed of convergence for a traditionally non-frontier economy like Greece. Secondly, it provides evidence regarding the impact of standard factors, such as R&D investment, trade and human capital on TFP growth of Greek manufacturing industries. Thirdly, the present study introduces some variables as potential sources of productivity growth that have attracted little attention in the empirical convergence literature. The chapter is organized as follows: section two provides a review of the literature regarding the sources of TFP

[5] Redding et.al (2005) provides a detailed discussion regarding the similarities of the present concept of

growth; section three presents an analytical framework for the convergence scenario and a discussion about the measurement of TFP; section four presents the econometric specification of the analysis and the main results; section five provides a sensitivity analysis to check for the robustness of the principal findings and section six concludes.

2. Sources of Productivity Growth

A body of empirical work has examined the relationship between R&D-the principal source of innovation- and productivity growth. Studies that confirm a positive effect of R&D investment on productivity growth include Griliches (1980) and Griliches Lichtenberg (1984) among many others. This studies use evidence either from firm or from country level highlighting mainly the fact that domestic investment can act as a conduit for productivity improvements and cost reductions[6]; however, studies by Helpman and Grossman (1991) and by Helpman and Coe (1995) address the issue to what extent R&D investment initially conducted abroad can serve as a source of productivity growth in other countries. Evidence provided by the above papers verifies that gains from R&D are multifaceted. A country can get benefits from its own R&D effort but at the same time can exploit positive spillovers by imitating R&D outcomes of other countries. The debatable issue in the literature regarding the influence of R&D on productivity growth refers to the accurate mechanism through which gains from R&D initially conducted abroad are transmitted across countries.

One of the most prominent scenarios is that foreign R&D is diffused to other countries via trade. When a trade partner devotes substantial resources in R&D activities then the importing country can have multiple benefits from trade; firstly, static gains are always present representing increases in welfare due to specialisation but also dynamic gains are derived from imitation of new technology already incorporated in the imported

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convergence with the classical ideas of σ and β convergence.

[6] Linking this argument with stylized facts at the industry level, Spence (1984) assumes that firm's R&D investment provides positive spillovers in the performance of rival firms within the industry, leading to an increase in industry's overall performance. Simultaneously, spillovers generate free-rider problems affecting negatively the decision of a firm to invest in R&D. This feature of diminishing returns of R&D is more systematically explored in the sensitivity analysis of the empirical section later in the chapter.

commodities. For the dynamic effect to take place, trade should take place in raw intermediate inputs rather than in final goods. Exports have also some important positive spillovers. Exporting provides a static benefit because domestic producers can exploit economies of scale due to a larger market, while from a more dynamic perspective exporting brings domestic producers in contact with international best practices (i.e. this effect is known in the associated literature as learning-by-exporting), this set of gains is very similar to those acquired from pure exercises of learning by doing.

As far as empirical evidence is concerned about the above arguments, Keller (1998, 2000) analyses whether imports of intermediate inputs can trigger productivity performance. The general finding of his studies is that import penetration enhances important positive effects for total factor productivity growth confirming that import flows incorporate effects from foreign R&D activity[7]. Keller's model concludes that R&D stocks in the countries of his sample have significant and positive influence on the TFP level of the receiving country. As far empirical evidence is concerned about the learning by exporting hypothesis, Clerides et al. (1998) and Bernard and Jensen (1999) conclude that there is no evidence for such a hypothesis at least after utilising firm level data. This result is also found in Xu (1996) after using country level data[8]. A convincing answer for the lack of evidence concerning the learning-by-exporting hypothesis is focused on the causal nature of the two variables. The current research agenda addresses the question whether exports improve productivity; while, the causality might be true in the opposite direction. In fact Clerides et al. (1998) and Bernal and Jensen (1999) find no

[7] Kneller (1998) provides robust evidence about the import-learning hypothesis however in his study there is no evidence regarding the composition of imports. That is imports enhances positive effects regardless what sort of materials a country imports. In contrast, Kneller (2000) certifies the same argument about imports and productivity but also provide evidence for the composition of imported commodities concluding that it does matter for TFP growth.

[8] Evidence for industry level data for the exporting productivity hypothesis is rather poor. A work about effects of exporting on productivity at the industry level is in progress in another paper of the present author. Some recent studies that they have analysed the issues using industry data are Anderson (2001) and Fu (2004). Findings appear to be rather contradictory; the former study finds positive exporting effects of productivity growth for Swedish manufacturing industries while the latter finds no evidence for Chinese industries.

substantial effects from exporting to productivity but they support a self-selection hypothesis in which productive firms are those that become exporters.[9]

In the discussion so far, special emphasis is given for the role of trade as a technology transmitter of foreign innovation (i.e. innovation that is initially developed abroad). The scenario regarding the contribution of R&D to productivity growth is incomplete if one ignores the multi-faced role of domestic innovation. The standard impact of domestic R&D is to accelerate the growth of productivity but even if this direct effect is weak, domestic innovation ensures that the domestic economy has the minimum level of technical expertise and technological *know-how* to absorb technological advancements form abroad[10]. This multifaceted role of domestic R&D is more systematically addressed in Griffith et al. (2004), where significant empirical evidence is also found for a panel of OECD countries regarding the potential of domestic R&D to affect the absorptive capacity of the domestic economy.

The discussion above relies on some stylized factors that literature highlights as sources of TFP growth. Certainly, the sources of productivity growth are not limited only to the variables of innovation and trade. The present study extends the analysis including some factors that reflect the structure and trends in the domestic market, namely rigidities in labour markets and the degree of concentration within industries. Obviously, it is not claimed that the impact of these variables on TFP growth has not been addressed in other studies, but the present study addresses the impact of these variables within a framework of productivity convergence.

A flexible labour market allows resources to move easily and costlessly within the economy thus promoting efficient management of resources, which might be a crucial

[9] Certainly, there are papers that find significant effect from exporting to productivity. The reason why empirical findings diverge from each other lies to the fact that countries under study experience different level of development. This type of disparities can explain to a large degree why in some studies there are positive knowledge spillovers from exporting while in some other they do not. For instance in a highly industrialised country very close to the international a frontier there is little scope for knowledge spillovers while in less developed country distance form the frontier is quite large and thus the margin for substantial knowledge spillovers are bigger.

[10] A similar argument is made by Acemoglu and Zillibotti (2001) for human capital.

engine for positive productivity shifts. In the literature there are various measures regarding the regulation of labour markets. Scarpetta et al. (2000) provide a summary of measures for the product market and employment regulation. This set of measures is particularly useful in a cross-country context since they refer to differences across countries, while in the present study this measure is uninformative because any change in the regulation affects all industries in the same direction. The present study uses the minimum wage ratio to capture the effects of costs in labour input, which to some extent can be a disincentive for entrepreneurship and also to reflect the bargaining power of trade unions, which in principal has a negative effect in the optimal allocation of resources[11]. Another domestic factor that affects the growth of productivity is the level of competition existing in the domestic market. The well-known argument in economics is that perfect competition is the ideal market structure because it ensures an efficient allocation of resources and produces the biggest amount of surpluses for both consumers and producers. This argument is widely inferred as a positive link between competition and productivity performance. Furthermore, Vickers (1995) points out that innovation is generally promoted more effectively in competitive markets, implying that a share of the efficiency gains can be devoted to innovative activity. The productivity competition relationship should be treated with special care since its empirical confirmation is not always clear due to potential endogeneity between the two variables. Nickell (1996) mentions that if a firm is initially productive this leads the firm to gain a larger market share in the long-run; however in his study the evidence emerged suggests that market power generates a reduced level of productivity and more importantly an increased degree of competition is associated with rates of TFP growth. This evidence cannot be viewed as conclusive as there are studies, Caves (1987) among others confirming that

[11] This variable is only a proxy and thus it is likely to be incomplete and powerless to illustrate all the possible ways through which s stringent labor market affects productivity. If labour legislation is over protective concerning workers then inefficient firms cannot easily make reforms towards a more efficient reallocation of resources (i.e. including firing employees), which might affect productivity of the whole industry. In addition to this, entry of new firms is strongly discouraged due to this strict legislation. In a similar argument, trade unions with strong bargaining power sometimes are able to achieve collective wage agreements that lie far above the completive value of marginal product of labour. As a result, workers are over –paid implying that financial resources are devoted for labour costs while they could have been used to R&D investment or other projects that stimulate productivity. Unfortunately, this type of ideas are very broad and the current measure of labour market rigidity is too limited to inform us separately whether these effect exist, consequently the lack of more informative data especially at the industry level force us to “stuck” to the current measure of labour market rigidities.

efficiency in the market is independent from the degree of concentration. Which of the above arguments is consistent with Greek manufacturing data[12] is examined in the empirical section followed together with a more systematic consideration of the endogeneity issue between productivity and concentration.

3. Analytical Framework

Consider a country $j \in [0, F]$, producing an output in industry *i* at time *t*. Production is characterised by constant returns to scale and takes the form of a Cobb-Douglas production function:

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

Y measures value added and the inputs include capital stock *K*, labour L. Parameter A represents a measure of technical efficiency in a Solow manner, 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.

For the purposes of the present analysis, at a given point in time *t*, one of the countries *j* will have a higher level of TFP and thus this country is specified as the Frontier economy indexed by *F*, in the present empirical model this country is Germany and the follower economy is Greece denoted by *j*. Later in the paper, the calculation of TFP levels indicate that this assumption is not arbitrary as it seems since the TFP level in German industries is higher than TFP level in Greek industries.

In Bernard and Jones (1996a, 1996b), $A_{j,i,t}$ is primarily modeled as a function of either domestic innovation or technology transfer from the frontier country. Therefore, a general formulation of the efficiency parameter *A* in industry *i* of country *j* is:

[12] Tsekouras and Daskalopoulou (2006) already provide some evidence for the case of Greece, finding that productive efficiency is unaffected from the degree of concentration in the market. The empirical evidence of this study, though, is focused on a smaller group of industries and for a shorter period compared to the present chapter.

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

In equation (2) parameter γ represents the rate of innovation depending on industry-specific factor while parameter λ denotes the change in TFP with respect to technology transfer from the frontier. As it stands 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

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

Combining equation (2) and (3) yields the following relationship:

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

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

$$\Delta \ln\left(\frac{\bar{A}_{i,j}}{\bar{A}_{i,F}}\right) = \frac{\gamma_{i,j} - \gamma_{i,F}}{\lambda_{i,j}} \tag{5}$$

Equation (5) states that in steady state equilibrium, relative TFP depends on the rates of innovation in the non-frontier economy *j*, in the frontier economy F and in the speed of technological convergence between the two economies λ. From equation (5) is also implied that country *j* remains technologically behind in a steady state equilibrium, that is $\ln\left(\frac{\bar{A}_{i,j}}{\bar{A}_{i,F}}\right) < 0$ when $\gamma_{i,j} < \gamma_{i,F}$. In words, the last two inequalities describe that in steady state equilibrium technological frontier country *F* remains as such as long as the rate of innovation in country *F* is higher than the rate of innovation in country *j*.

A further issue regarding equation (2) is what are the specific factors determining the level of industry *i*'s innovation. As it stands in equation (2), $\gamma_{i,j,t}$ $\lambda_{i,j,t}$ are the parameters of the model; however, the propositions of the endogenous growth theory, implies that there are particular factors determining these parameters. Among factors that affect $\gamma_{i,j,t}$ $\lambda_{i,j,t}$ are R&D, trade, human capital, rigidities in labour market and the degree of domestic competition.

Measuring Total Factor Productivity

As discussed in the previous section the measure of productivity used in the present study is total factor productivity (TFP). The calculation of this index is based on a Tornqvist index number approach as has been initially developed by Caves, Christensen and Diewert (1982). This TFP index can be directly derived by 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[13]. From the Tornqvist index, the TFP growth in industry *i* is defined as:

$$\ln\left(\frac{A_{i,j,t}}{A_{i,j,t-1}}\right) = \ln\left(\frac{Y_{i,j,t}}{Y_{i,j,t-1}}\right) - a_L \ln\left(\frac{L_{i,j,t}}{L_{i,j,t-1}}\right) - (1-a_L)\ln\left(\frac{K_{i,j,t}}{K_{i,j,t-1}}\right) \qquad (6)$$

The notation remains the same as in the previous section, where *j* and *t* refers to country and time, respectively. Output *Y* is measured by value added, *L* is a measure of labour input and *K* denotes capital stock. The input measures of equation (6) are weighted by their shares in value added under the assumption of constant returns to scale. The labour share is defined as: $a_L = \frac{a_{i,j,t} + a_{i,j,t-1}}{2}$ .Sector-specific deflators are used for value added and investment in capital assets as these provided by OECD-STAN[14]. The reference year in the figures of TFP growth in equation (6) is 1995.

As appeared in equation (2) and (4) of the previous section, apart from industry *i*'s TFP growth, another index is necessary to express industry *i*'s TFP in Greece relative to industry *i*'s in Germany. The relative index of TFP level is defined in a similar way as:

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[13] The OECD Manual (2001) provides an extensive discussion regarding the different approaches used in productivity measurement.
[14] Data for Gross fixed capital formation, capital deflator, number of employees and value added deflator for years prior to 1995 are taken from KLEMS database; an appendix provides a detailed summary of data sources.

$$\ln\left(\frac{A_{i,j,t-1}}{A_{i,F,t-1}}\right)=\ln\left(\frac{Y_{i,j,t-1}}{Y_{i,F,t-1}}\right)-a_L\ln\left(\frac{L_{i,j,t-1}}{L_{i,F,t-1}}\right)-(1-a_L)\ln\left(\frac{K_{i,j,t-1}}{K_{i,F,t-1}}\right) \quad (7)$$

where j and F are Greece and Germany and the labour share is now defined as: $a_L=\frac{a_{i,j,t-1}+a_{i,F,t-1}}{2}$.

The construction of capital stock is based on a standard perpetual inventory method given by the following formula: $K_{i,j,t}=(1-\delta)K_{i,j,t-1}+I_{i,j,t-1}$, where the Greek letter δ denotes the capital depreciation rate, defined at the 10% for all industries and I stands for the investment in gross fixed capital formation. The initial capital stock is given by the following formula:

$K_{i,j,1980}=\frac{I_{i,j,1980}}{g_i+\delta}$, where g is the average growth rate in industry i's investment over the whole period and year 1980 is the first year with data available in investment of gross capital.

A common problem in industry's TFP comparisons across countries is the measure of both output and inputs in a common currency, in the present study though this does not appear as a problem since OECD-STAN provides data for Greece and Germany in a common currency. Values for the whole period are converted into euros using the annual exchange rate of the year that country enters the common currency union. Apart from issues refers to measuring values in a common currency, there are some issues concerning a consistent measurement of TFP index. Productivity is strongly procyclical and thus it is affected by movements of the business cycle, to take into account the above effect, TFP indices are adjusted for capacity utilization. There are two main ways to do these adjustments the first one is to include an explanatory variable of capacity utilization in the empirical econometric specification, this approach is followed by Redding et al. (2005), an alternative way is to adjust the calculated capital stock by an index of capacity utilization as proposed by Dollar and Wolff (1993). Furthermore, the TFP indices in equations (6) an (7) adjust the number of employees with average amount of hours worked in each industry[15]. A necessary extension might be to adjust TFP for quality differences in the labour input. This requires information about the number of skilled and unskilled workers as well as information about their wages, unfortunately these data do not exist for Greek manufacturing industries for the whole period under study and thus labour is measured as a homogenous input.[16] After the adjustments discussed above the final TFP growth index takes the form:

$$\ln\left(\frac{A_{i,j,t}}{A_{i,j,t-1}}\right) = \ln\left(\frac{Y_{i,j,t}}{Y_{i,j,t-1}}\right) - a_L \ln\left(\frac{\tilde{L}_{i,j,t}}{\tilde{L}_{i,j,t-1}}\right) - (1-a_L)\ln\left(\frac{\tilde{K}_{i,j,t}}{\tilde{K}_{i,j,t-1}}\right) \tag{8}$$

$\tilde{L}_{i,j,t} = h_{i,j,t}L_{i,j,t}$ and $\tilde{K}_{i,j,t} = u_{j,t}K_{i,j,t}$

where h denotes the average annual hours worked and u denotes the percentage of capacity utilization. No industry-specific information is available for capacity utilization since data for this variable are reported for the whole manufacturing sector implying that the business cycle affects all industries within a country in the same way[17]. This adjustment is likely to affect productivity measurements when comparisons occur between countries.

Annual TFP growth rates of the aggregate manufacturing sector for the whole period are shown in table 1 along with the relative TFP level. Greek manufacturing sector is grown on average by 1.72% in the sample period while the German manufacturing experiences clearly a lower rate of productivity equals to 1.44%. This preliminary table suggests that the non-frontier economy has a higher productivity growth as predicted by the theory. The last column of table 1 verifies that Germany is correctly assumed as the frontier country since the TFP level in German industries is always higher. Figures in the last column can be interpreted in the following manner: Greek manufacturing is 22% percent

[15] Data for average hours worked in each industry are taken by the database of Groningen Growth and Development Centre (GGDC).

[16] Andersson (2001) documents that these differences might make an important difference in the measure of TFP across countries and a similar argument is appeared in Redding et al. (2005). Given that the composition of labour is fixed across years, the lack of data for skilled and unskilled workers is an effect that can be tackled effectively in a fixed affect model in the econometric specification.

as productive as Germany in 1980, while in the last year of the sample Greek and German TFP levels are very close. Data report a clear evidence of convergence, as it is also confirmed in table 2, where relative TFP values are reported by industry at the beginning and at the end of the sample period. The only industry in which Greece has a TFP advantage in 1980 is machinery and equipment while the remaining industries, at the end of the period have covered much of the productivity gap. Interestingly, the Greek industries of food, petroleum, other mineral products and other transport equipment are more productive than their counterparts at the last year of the sample. The econometric analysis of the next section investigates whether the potential of technology transfer is a source of productivity growth for Greek manufacturing industries.

Table 1 Growth Values and Relative Levels of TFP

Year	$TFPG_{Germany}$	$TFPG_{Greec}$	RTFP
1980			22.20%
1981	-0.20%	14.10%	17.20%
1982	2.40%	13.20%	15.80%
1983	3.00%	18.00%	21.00%
1984	2.30%	17.60%	21.30%
1985	3.30%	23.70%	24.10%
1986	4.90%	11.90%	25.00%
1987	-3.80%	6.50%	24.80%
1988	4.20%	24.10%	29.10%
1989	2.00%	15.60%	32.40%
1990	5.50%	9.90%	47.10%
1991	5.20%	15.20%	48.00%
1992	-3.90%	5.80%	43.90%
1993	3.60%	19.50%	45.10%
1994	5.50%	8.10%	44.00%
1995	-0.30%	2.80%	44.60%
1996	6.90%	10.20%	46.70%
1997	3.20%	0.60%	44.80%
1998	3.90%	10.20%	48.20%
1999	-0.90%	4.50%	52.30%
2000	6.30%	15.20%	55.30%
2001	2.40%	9.30%	60.30%
2002	1.10%	5.60%	67.30%
2003	-23.40%	10.40%	95.70%
Mean	1.44%	11.72%	41.10%

TFPG is an index of TFP growth adjusted for capacity utilization and hours worked
RTFP is an index of relative TFP level between Greece and Germany; figures displayed are the exponential

[17] Data for Capacity utilisation are obtained from OECD-Main Economic Indicators and provided on a quarterly basis.

values of equation 7 in the text adjusted for capacity utilization and hours worked

Table 2 Relative TFP by Industry in 1980 and 2003

Industry	1980	2003
Food products, beverages and tobacco	5.74%	102.92%
Textiles, textile products, leather and footwear	4.51%	45.10%
Wood and products of wood and cork	4.50%	81.67%
Pulp, paper, paper products, printing and publishing	16.55%	139.04%
Coke, refined petroleum products and nuclear fuel	1.61%	301.47%
Chemicals and chemical products	4.93%	64.07%
Rubber and plastics products	7.57%	71.38%
Other nonmetallic mineral products	7.13%	119.81%
Basic metals	7.53%	60.75%
Fabricated metal products, except machinery and equipment	253.13%	54.81%
Machinery and equipment, n.e.c.	5.13%	33.06%
Electrical machinery and apparatus, nec	2.86%	67.44%
Radio, television and communication equipment	8.22%	83.02%
Medical, precision and optical instruments, watches and clocks	13.33%	56.13%
Other transport equipment	9.93%	175.31%
Manufacturing nec	2.55%	63.19%

4. Econometric Model and Results

The present section specifies the econometric model applied to estimate the sources of productivity growth in Greek manufacturing industries. The formulation of the model is principally based on the theoretical model already presented giving emphasis to the catch-up process between industries across countries. The empirical convergence equation is an equilibrium correction model (ECM) represented by an ADL (1,1) process[18], in which the level of productivity in industry *i* is co-integrated with productivity in the frontier country *F* as follows:

$$\ln A_{i,j,t} = \beta_0 + \beta_1 \ln A_{i,j,t-1} + \beta_2 \ln A_{i,F,t} + \beta_3 \ln A_{i,F,t-1} + \omega_{i,j,t} \tag{10}$$

where ω stands for all the observed and unobserved effects that may influence TFP and it is further decomposed as:

$$\omega_{i,j,t} = \sum_k \gamma_k Z_{i,j,t-1} + \rho_i + d_t + e_{i,j,t} \tag{11}$$

The summation in the right-hand side of (11) includes all the observed factors affecting TFP while ρ and d stand for industry and year specific effects, respectively. Assuming that the long-run homogeneity $(1-\beta_1 = \beta_2 + \beta_3)$ holds in (10), then its transformation gives:

$$\ln \Delta A_{i,j,t} = \beta_0 + \beta_2 \ln \Delta A_{i,F,t} + (1-\beta_1)(\ln A_{i,F,t-1} - \ln A_{i,j,t-1}) + \omega_{i,j,t} \tag{12}$$

[18] Further details about estimation issues of an ADL (1, 1) model can be found in Perasan and Shin (1997) and Hendy (1995). This application of an ADL model in a productivity convergence framework is initially used by Bernard and Jones (1996a).

In equation (12), the dependent variable is industry *i*'s TFP growth in the non-frontier economy- Greece- while the right hand-side includes industry *i*'s TFP growth in the frontier economy and a term of technological gap between country *j* and *F* in industry *i*. Substituting (11) into (12) gives a specification in which R&D, trade and human capital influence the rate of TFP growth in the non-frontier economy both directly and through the rate of absorptive capacity. Finally, the panel structure of the model should be taken into account the existence of heterogeneous factors that affect TFP growth. After these considerations, the estimable equation takes the following form:

$$\ln \Delta A_{i,j,t} = \rho_{i,j} + \alpha \ln \Delta A_{i,F,t} + \gamma Z_{i,j,t-1} + \lambda \left(\ln \frac{A_{i,F,t-1}}{A_{i,j,t-1}} \right) + \mu Z_{i,j,t-1} \left(\ln \frac{A_{i,F,t-1}}{A_{i,j,t-1}} \right) + e_{i,j,t} \qquad (13)$$

In (13) α captures the effect of TFP growth in the frontier economy on the non- frontier economy, λ indicates the speed of technological transfer, Z includes other factors that have a direct effect on TFP growth such as: R&D, trade, human capital, labour market rigidities and concentration and μ measures the responsiveness of TFP growth after changes in the level of absorptive capacity. The latter variable is an interacted term between variables included in Z and TFP gap. A more detailed description about the definition of the previous variables as well as issues concerning data sources can be found in the appendix.

Equation (13) is a fixed effects specification; the term $\rho_{i,j}$ stands for time-invariant industry dummies. A possible method to estimate (13) is to use a least squares dummy variable approach (LSDV), which is basically an OLS including a set of dummy variables. A potential problem regarding this approach is that industry fixed effects might be correlated with other covariates in the right–hand side thus producing biased estimates. Instead, a within group estimator avoids this problem by expressing all variables as deviations from their sectoral means. In the present case, the size of the panel[19] indicates that the fixed within group estimator is more preferable than an IV-GMM (Judson and Owen (1999)).

[19]After missing two years required for the construction of some variables, the panel consists of 22 years and 16 industries. This implies that the number of time series units is bigger than the number of cross-sections

The estimation of a cross-section time series model requires some assumptions regarding the process evolved by the error term $e_{i,j,t}$ in equation (13). Some of these assumptions are not met in the present data and thus a more systematic treatment is needed to provide unbiased estimates. Firstly, the model allows for a heteroscedastic error term across sections, $Var(e_{i,t}) \neq Var(e_{k,t})$ for any industry *i≠k*. Secondly, the model corrects for correlation in the disturbance terms across sections, $Cor(e_{i,t}e_{k,t}) \neq 0$ for any industry *i≠k*. Thirdly, the model controls for industry specific serial correlation, $Cor(\omega_{i,t}\omega_{i,t-1}) \neq 0$.[20]

Table (3) reports results from a within group estimator corrected for group wise heteroscedasticity, cross-sectional correlation and industry-specific first order serial correlation. Since industries are quite different in size, each observation is weighted by the industry's share in total manufacturing value added in the first year of the sample period as suggested by Redding et al. (2005). The dependent variable in all specifications is the growth of total factor productivity in manufacturing industries for the period indicated in the first row. In column (1), the dependent variable is regressed on the contemporaneous TFP growth in German manufacturing industry *i*, the TFP distance (i.e. $TFPgap = \log(\frac{A_{i,F,t-1}}{A_{i,j,t-1}})$ between Greece and Germany at year *t-1* in industry *i*, a trade variable and an interacted term of trade with *TFP gap*.

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and thus relying on Monte Carlo experiments conducted by Judson and Owen (1999), the FE within group estimator is a better choice than GMM.

[20] The software package used to estimate regressions throughout the paper is STATA 9. The specific estimator used by STATA for a FE within groups model and for correction of the associated misspecification errors is the Panel Corrected Standard Error Estimator developed by Beck and Katz (1995).

Table 3 Preliminary results - Fixed Effects Within-Groups Estimator for the Sources of TFP Growth

Period	1982-2003 (1)	1982-2003 (2)	1982-2003 (3)	1981-2003 (4)	1982-2003 (5)
$\Delta \log TFP_{i,F,t}$	0.088 (1.2)	0.079 (1.08)	0.089 (1.2)	0.106 (1.46)	0.085 (0.91)
log TFPgap	0.05 (6.36)***	0.053 (7.17)***	0.062 (4.70)***	0.107 (3.62)***	0.042 (3.13)***
$\log(Trade/X)_{i,t-1}$	-0.037 (3.10)***				
$(Trade/X)_{i,t-1}$*$TFPgap$	0.016 (3.33)***				
$(IMP/X)_{i,t-1}$		-0.024 (2.42)*			
$(IMP/X)_{i,t-1}*TFPgap$		0.014 (2.97)***			
$\log(EXP/X)_{i,t-1}$			-0.016 (1.06)		
$(EXP/X)_{i,t-1}*TFPgap$			0.089 (1.2)		
$\log(R\&D/VA)_{i,t-1}$					-0.011 (1.96)**
$(R\&D/VA)_{i,t-1}$ *TFPgap					0.804 (1.71)*
$\log(HCshare)_{i,t-1}$				0.074 (1.65)	
$HCshare_t*TFPgap$				-0.62 (1.02)	
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	366	366	366	381	340
Number of sectors	17	17	17	17	16
Absolute z statistics in parentheses; * significant at 10%; ** significant at 5%;*** significant at 1%					
Diagnostic Tests					
R-squared	0.222	0.2425	0.2265	0.2455	0.1564
Wald chi2(4)-P value	113.52 0.00	122.870.00	86.24 0.00	76.53 0.00	18.73 0.0009

Notes: All observations are weighted by industry's value added in manufacturing sector at period 1982; Estimates are based on a Fixed Effects within group estimator corrected for heteroscedasticity, cross-sectional correlation and industry specific serial correlation. Columns (1)-(4) consists of 17 industries, however industry of vehicles is omitted from all the forthcoming specifications due to lack of data in R&D.

The positive and statistically significant coefficient of the technological gap variable indicates that the further an industry lies behind the frontier, the faster is the rate of total productivity growth. The contemporaneous term of the TFP growth in the frontier economy has a positive sign although the coefficient is insignificant. Regarding the trade variable the pattern revealed is very interesting. The level variable carries a negative and statistically significant coefficient while the interacted term of trade with the *TFPgap* suggests that trade plays an important role in technology transfer. The sign of the trade variables are contradictory with each other and remain as such even if trade variable is decomposed into exports and imports. Note that both terms of exports are insignificant. Colum (4) examines the influence of human capital ($logHCshare_{t-1}$) measured by the share of workers with tertiary education in total labour force and its interacted term ($HCshare_{t-1}{*}TFPgap$). Results from this specification suggest that the level of human capital has a positive effect on total factor productivity growth as normally expected; however, this effect is not significant at conventional statistical levels.

Column (5) controls for the impact of R&D on the growth of total factor productivity. The pattern revealed is quite similar to the one emerged from the trade specification in column (1). The level term of R&D share appears with a negative coefficient and is statistically significant at the 5% percent level. This negative pattern is likely to indicate that expensive nature of R&D activity, which is somehow risky and uncertain since it needs time to implement R&D effort to pure productivity gains. Nonetheless, the interacted term is positive indicating that R&D intensity might have another role apart from directly boosting innovation. This preliminary pattern is consistent with the second face of R&D, which stresses the role of R&D intensity in improving absorptive capacity. Currently, this effect cannot be viewed as overwhelming-but it is proved so in the next specifications- given that the coefficient of the interacted term is marginally significant at the 10 %.

Table 4 presents results from a specification in which both trade and R&D variables are included along with their associated terms. In column (1), the autonomous technology transfer as measured by the relative TFP variable is positive and statistically significant at high confidence levels, confirming once again that a country, which falls far behind the frontier tends to grow faster. Concerning the other variables, trade level still has a negative sign as in table 3. The interacted term is still positive but not statistically significant. The R&D level continues to be negative as it is in table 3 but now it turns up with an insignificant coefficient. The interacted R&D term is positive and significant at the 5 % providing stronger support for the estimates of table 3. Column 2 introduces in the model the role of labour market rigidities on growth of TFP. As discussed earlier, stringency in the labour market can be an obstacle for productivity performance from many different aspects. These rigidities can be somehow captured in the ratio of minimum to median wage. Column (2) certifies that labour market rigidities have a negative influence on productivity growth as the ratio of minimum to median wage has a negative coefficient and marginally significant (t-value is 1.88). At the same specification, the autonomous technology transfer and the interacted term of R&D have a statistically significant coefficient. Column 3 presents results from a specification that includes a measure of domestic market concentration. Note that data for this variable are only available from 1993 onwards and thus the length of the panel is reduced by twelve years. As already pointed out, the interpretation of the coefficient of this variable is based on contradictory arguments. Industries with large market shares might experience substantial monopoly power hampering efficiency and allowing for slack, while at the same time a reverse argument suggests that when firms within industries dominate the market, they start operating in a higher scale of production, a fact that can be proved beneficial for overall industry's productivity. According to column 3, the latter argument gains support in Greek manufacturing sector since the lagged variable of domestic concentration comes up with a positive coefficient. Nonetheless, this effect is not strong because statistical significance lies far below conventional levels. The only remarkable difference between specifications 1 and 2 is that the technology gap variable is insignificant[21] likewise with the labour market variable while the interacted term of trade with the technology gap becomes significant at the 10% percent level.

[21] Given that the period is now shorter, the insignificance of the TFP gap variable is expected since many industries have already covered a big part of the technological gap, eliminating noticeably the potential of technological transfer.

Table 4 Benchmark Specifications FE-IV Estimates for the Sources of TFP Growth

	1982-2003 (1)	1982-2003 (2)	1993-2003 (3)	1982-2003 (4)	1993-2003 (5)
	Within Group-Fixed Effects	Within Group-Fixed Effects	Within Group-Fixed Effects	IV- FE	IV-FE
$\Delta \log TFP_{i,F,t}$	0.081	0.097	0.019	0.092	-0.042
	(1.08)	(1.31)	(0.23)	(1.31)	(0.36)
log TFPgap	0.056	0.037	0.029	-0.047	0.210
	(5.85)***	(3.31)***	(0.78)	-1.21	(1.01)
$\log(Trade/X)_{i,t-1}$	-0.027	-0.028	-0.04	(0.109)	0.133
	(2.12)**	(2.33)**	(1.71)*	(2.13)**	(0.27)
$(Trade/X)_{i,t-1}$*$TFPgap$	0.002	0.002	0.021	0.045	0.184
	(0.52)	(0.48)	(1.9)	(2.40)*	(0.27)
$\log(R\&D/VA)_{i,t-1}$	0	0.002	-0.001	0.013	0.067
	(0.05)	(0.3)	(0.09)	(0.83)	(1.27)
$(R\&D/VA)_{i,t-1}$ *TFPgap	0.916	0.984	1.023	0.924	-1.708
	(2.06)**	(2.35)**	(2.53)**	(2.10)**	(1.27)
(Min Wage/Median Wage)$_{t-1}$		-0.055	-0.069	-0.123	-0.365
		(1.88)*	(1.02)	(2.62)***	(2.13)**
$\log CR_{i,t-1}$			0.022		-0.485
			(1.49)		(1.69)*
Industry Effects	Yes	Yes	Yes	Yes	Yes
Observations	326	321	156	278	123
Number of sector	16	16	16	16	16
Absolute z statistics in parentheses; * significant at 10%; ** significant at 5%;*** significant at 1%					
Diagnostic Tests					
R-squared	0.2376	0.2113	0.08	0.071	0.06
Wald chi2(4)-P value	103.56 0.000	118.95 0.000	29.30	166.40	122.52
Serial Correlation				14.443 (0.0017)	5.872 (0.028)
Sargan Test				9.289 (0.10)	2.245 (0.895)

Notes: All observations are weighted by industry's value added in manufacturing sector at period 1982; Estimates in columns (1), (2), (3) are based on a Fixed Effects within group estimator corrected for heteroscedasticity, cross-sectional correlation and industry specific serial correlation. Specifications in columns (4) and (5) are IV–FE estimations. In column (4) and (5), the endogenous variables are TFPgap, $\log(Trade/X)_{i,t-1}$, $(Trade/X)_{i,t-1}$*$TFPgap$ and $\log CR_{i,t-1}$. The instruments used are

$\log(\frac{A_{i,F,t-3}}{A_{i,j,t-3}})$, $\log(\frac{A_{i,F,t-4}}{A_{i,j,t-4}})$, $\log(Trade/X)_{i,t-3}$, $\log(Trade/X)_{i,t-4}$, $(Trade/X)_{i,t-3}$*$TFPgap$, $(Trade/X)_{i,t-4}$*$TFPgap$, $\log CR_{i,t-2}$ and $\log CR_{i,t-3}$. The serial correlation test is based on Wooldridge (2002); the null hypothesis is no serial correlation. The Sargan test is a statistic for the validity of instruments following the Chi-squared distribution; in the current model n equals to 5 and clearly suggest to accept the null hypothesis that the instruments re valid.

A further concern regarding the econometric analysis of the present chapter is the existence of substantial measurement errors. The present measurement of TFP controls for some standard corrections suggested in the literature of TFP measurement, such as hours worked and capacity utilization.[22] Apart from the standard measurement errors that might exist in the TFP variable, another issue that arises in the econometric estimation and needs special treatment is the potential endogeneity between the left-hand side variable and the right hand side variables in equation (13). Note that the growth of TFP in the left hand side is measured as $\ln\left(\frac{A_{i,j,t}}{A_{i,j,t-1}}\right)$ whereas the right hand side relative TFP level is $\ln\left(\frac{A_{i,F,t-1}}{A_{i,j,t-1}}\right)$, this indicates that shocks in the level of TFP in country *j* at year t-1 affect both growth of TFP and the initial distance from the frontier. This realization enhances an endogeneity problem between the growth of TFP and the TFP gap variable. To control for this endogeneity problem as well as to correct for any potential measurement bias already embodied in the TFP measurement, instrumental variable (IV) estimation is considered. As instruments of TFP gap at *t-1* can be used longer lagged values of the TFP distance variable. In the present study, one of the central hypotheses is to investigate whether there is substantial evidence for the trade-led growth hypothesis. Nevertheless, the neoclassical trade theory identifies as determinants of trade flows differences in the level of productivity across countries; this proposition implies that the link of trade with productivity might run in the opposite direction. Therefore, growth of

[22] There are some other issues discussed in the literature about potential bias in the measurement of TFP. These are different types of workers in the measurement of labour input, the existence of price marks up and problems derived from double-checking. Some of them are unlikely to be addressed in the present work due to lack of data availability, this is the case especially for different types of labour. In the next section, it is provided a test for the bias captured from double-checking in the construction of TFP. This is that R&D inputs, especially R&D personnel are sometime double counted in the standard measure of labour input. After extracting R&D personnel from the total number of employees in the TFP calculation, the TFP figures are almost unchanged.

TFP in manufacturing industries might be viewed as a source of trade raising a similar issue of endogeneity between TFP growth and trade. As instruments of the endogenous trade and relative TFP variables can be used their higher order lagged values. The latter can be considered as valid instruments as long as they are uncorrelated with the TFP growth error term in equation (13). The fulfillment of this requirement can be checked by two complementary methods, the first way is to check whether the residual in TFP growth equation in (13) is serially correlated. An appropriate test for panel data serial correlation is specified by Wooldridge (2002). This test checks for autocorrelation in the residuals assuming that the latter follows an AR (1) process. The Wooldridge test shows that it is not possible to accept the null hypothesis and thus there is some evidence for first order serial correlation in the model[23]. Given that, TFP gap is already expressed in one-year lag then as valid instruments can be used third and fourth order lags,$TFPgap_{t-3}$ and $TFPgap_{t-4.}$ The second test applied refers to the validity of instruments under the Sargan test of overidentifying restrictions. This test computes a statistic for an overidentifying restriction in which the number of regressors is smaller than the number of instruments. Under the null hypothesis, the equation is correctly specified and the set of instruments is valid. Column (4) reports results after controlling for endogeneity in TFP gap, trade and trade interacted variable. The third and fourth order lags of the endogenous variables are a valid set of instruments as indicated by the Sargan test (p-value 0.10).

The results produced in columns (4) and (5) rely on a 2SLS IV-FE estimation. Specifications in columns (2) and (4) constitute the preferable specifications of the chapter and the main inference discussed later in the chapter is based on them[24]. Comparing results between the IV and the within groups estimator the main differences emerges in the coefficient of the TFP gap. It is not any more statistically significant while

[23] The implementation of the Wooldridge test follows the standard procedures used to test for the existence of autocorrelation in the idiosyncratic term. Equation (10) is initially estimated in first differences and then contemporaneous residuals are regressed upon one year lagged residual like a standard AR (1) model. The null hypothesis of the Wooldridge test specifies that the coefficient of the lagged residual equals 0.5. Rejecting the null indicates that first order serial correlation exists in the model.

[24] Specifications in (3) and (5) include the concentration variable and from this respect should be more informative; however, due to short series in concentration variable, specifications in (3) and (5) are only indicative since the original panel is reduced by 12 years.

in column (4) turns up with a negative sign. In contrast the interacted trade term is now informative about changes in TFP growth since the coefficient is statistically significant at the 5% level. The positive and statistically significant pattern of the interacted R&D variable is also maintained. The differences revealed by an IV estimation suggest that when one treats more systematically the endogeneity issues of relative TFP and trade, then the role of autonomous technological transfer seems to be of not particular interest in the movements of TFP growth. The indirect effects of technological transfer has been now reinforced indicating that technology transfer is accelerated when Greek manufacturing industries have the appropriate level of absorptive capacity and trade involvement in order to facilitate the technological advancements of their frontier counterparts. From this respect, trade and R&D investment play a very important role in TFP growth. This effect is somehow different from the result documented in Khan (2006), which finds that the coefficient of the autonomous transfer remains always significant[25] even after treating it as endogenous, while the latter study fails to provide evidence for the role of trade and R&D as engines that improve country's absorptive capacity. Results of the present study are consistent with findings in Cameron (2005) and Griffith et al. (2004) providing additional support to the argument that in general the role of R&D is underestimated since traditional studies emphasize only the direct role of R&D as a channel of innovation taking no notice of the second face of it in improving a country's ability to imitate foreign technology.

Finally, the strong and negative impact of labour market rigidities persists on the growth of total factor productivity in the IV estimation and it is even stronger compared to the coefficient in column 2 (i.e. it is significant at 5%). As already commented (footnote 10), the current study cannot perfectly define a variable that captures all the institutional factors that determine the level of stringency in labour market. To the extent that the ratio of minimum to median wage is more likely to reflect the bargaining power of trade unions, then the outcome clearly pointed out from the present study is that trade unions in Greece are quite powerful. This means that collective wage agreements determine an actual wage that in some industries lie far above the competitive level of marginal

[25] Although, this study documents that the effect of autonomous technological transfer is smaller after

product of labour. In this context, a powerful trade union can be also connected with a protective employment legislation that has negative effects on the skill upgrading of labour force. From this point of view, when firms wish to achieve a high level of dynamic efficiency should recruit personnel that can adopt in the new technological standards. If legislation is too strict, firms do not recruit easily people from the external market, instead they need to re-train the existing personnel to acquire the necessary skills, but with wages already above the completive level, additional training of the personnel causes further increases in labour costs and thus firms are unable to follow the new technological changes (Scarpetta et al. (2006)). This conclusion cannot be directly drawn for the Greek manufacturing sector since the variable used is not a pure measure of the employment protection legislation (EPL); nonetheless, the above arguments implies an underlying process that might drive the negative relationship between the minimum to median wage ratio and TFP growth.

Summarizing the results so far, table 3 presents evidence from a preliminary analysis and shows clearly that as country falls far behind the frontier then it experiences a more rapid growth of TFP. From the preferred specification of the chapter, table 4 (columns (2) and (4)), the main message is that R&D matters more for country's absorptive capacity rather than the direct stimulation of productivity growth. Similarly, labour market rigidities have a negative impact on TFP growth. A positive effect is also documented for the interacted trade variable in the IV estimation[26]. Before proceeding with some sensitivity tests about the robustness of the current results a useful task is to interpret the absolute coefficient of the TFP gap variable. Emphasis is given to coefficients in column (1) and (2) in table (4), where the speed of adjustment is 5.6% and 3.7%, respectively. These coefficients imply that the catch up process in the Greek manufacturing industries towards their German counterparts is rather slow. This argument becomes more transparent taking into account findings from other studies regarding the above coefficient. Particularly, in a very similar specification as it is table 4, Cameron (2005)

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controlling for potential endogeneity.

[26] The fact that the interacted trade term is negative in the within groups estimator column (2) lies on the fact that trade measure includes both imports and exports components and this yields somehow contradictory patterns. Running regression in column 2, including only the import share as indicator of trade the sign of the variable is positive, still though it remains insignificant.

finds that the speed of adjustment in Japanese industries towards their US counterparts is 6.3%, while, Khan (2006) reveals a speed of adjustment of French industries towards US counterparts in the order of 6.5%[27].

5. Sensitivity Analysis

Several issues are involved regarding the results presented in the previous section. After controlling for potential endogeneity in key variables, the new estimates reveal that the major change in the pattern of the results is that the coefficient of autonomous transfer losses much of its statistical significance while the interacted terms are significant in almost all the IV specifications. However, endogeneity is not the uniform problem of measurement that might be present in the present econometric specifications, several measurement problems might exist regarding either TFP or some other variables. Apart from measurement errors, some results obtained above are contradictory to the theoretical expectations and therefore some further analysis is required to check whether the findings of the previous section yield a particular structural pattern or simply reflect a problem in the definition of specific variables. The present section conducts some sensitivity tests seeking to test for the robustness of the results in equation (13).

Tables 3 and 4 are unable to reveal any significant impact of trade on TFP growth. This finding is in opposition with propositions of endogenous growth theory but it also diverges from findings in other empirical studies. To analyse further this result, two points should be taken into account, firstly more emphasis is given to the idea discussed in the introduction regarding the strong similarity between the concepts of learning-by-doing and learning-by-exporting. If these two processes have many common features then learning-by-exporting might be described more accurately by a non-linear relationship. Going back to the seminal work of Arrow (1962), the key point suggested is

[27] Appendix provides a formal unit root test for stationarity to test whether the model specified in 10 is a good approximation of an equilibrium correction model.

that learning-by-doing is an accumulated product of experience and as such is subject to diminishing returns to scale. Accepting that dynamic gains from exporting are at work but they are not infinite implying that after a critical threshold further increase of export activity is unable to provide significant benefits[28]. Secondly, models developed by Young (1991) and Chaung (1998) emphasize the bounded nature of learning induced by trade. The latter studies suggest that learning by trading is critically determined by the pattern of trade (i.e. the types of goods traded) and the identity of the trade partner.

Appendix 3 replicates specifications (2) and (4) of table 4 after controlling for a non-linear relationship between trade and TFP growth as well as for a bounded nature of trade. Specification (1) presents results from a quadratic term of both trade share and the interacted term. The negative sign of trade share is eliminated while the interacted term is now appeared with a negative impact. However, these estimates cannot be viewed as informative since coefficients are far from statistically significant levels. The remaining specifications of the table shows results from a quadratic term of imports and exports share considering both a within –groups and an IV estimator. In the IV estimation, the instruments used are the second and third lags of the endogenous variables, and second the third lags of the R&D share. An interesting point is that there is a weak evidence for the bounded nature of learning induced by trade in specifications (2) and (4) for the reason that the quadratic share term is positive and statistically significant at the 10% level (t-values are 1.7 and 1.92 for the import and export share respectively). This can be viewed as evidence of a non-linear relationship between dynamic import and export gains and TFP growth. Nevertheless, these non-linear relationships cannot be viewed as overwhelming both because the coefficients of trade variables are statistically significant only at the10% and because after controlling for possible endogeneity, the coefficients of the quadratic trade terms are changed back to negative (columns (3) and (5)). Note that the interacted terms are in all specifications with statistically insignificant coefficients. Specifications (6) and (7) refer to estimates when trade only with G7 countries is considered. The ratio used is the sum of imports (exports) to G7 over the total amount of

[28] Similarly, the argument can be at work from the reverse side, exposure in international markets does ensure automatically learning benefits: instead, exporters need to reach a crucial threshold after which they can start experience substantial knowledge gains from exporting

imports (exports). The rationale of this specification is based on the idea that these countries are clearly more technologically advanced than Greece and thus increases in trade involvement of Greek industries with them can enhance significant knowledge spillovers. This specification does not offer any insight for the hypothesis that the identity of trade partners can generate positive learning shock that stimulates TFP growth. Overall, there is a weak evidence for a non-linear relationship between trade components and TFP growth, which disappears as IV estimation is applied; while learning effects do not depend on the identity of the trade partners.

A further check of robustness involves the measurement of R&D. The previous section relies on a flow measure of R&D; however, it seems reasonable to assume that knowledge is an accumulated process rather than a one – off effect . Therefore, R&D is also measured as a stock variable obtained by the standard inventory equation:

$$RDstock_{it} = (1-\delta)RDstock_{it-1} + RDexpenditure_{it}$$

$RDstock_{t-1}$ describes the accumulated stock up to period *t-1* and *RDexpenditure* denotes the expenditure on R&D conducted by industry *i* at the current year. The initial R&D stock in industry *i* is calculated using a benchmark equation proposed by Griliches (1981), which is identical to the formula applied to calculate benchmark physical capital stock previously. A standard dilemma encountered in the calculation of the above equation is a plausible assumption about the depreciation of the R&D stock. The present measure assumes a rate of 5%, admittedly this assumption is an arbitrary one; although, it will make no difference in the qualitative picture of the econometric results if it is assumed a rate of 10 or 2.5 percent. One of the robust results of the previous section is the positive coefficient of the R&D share interacted with the TFPgap. This positive coefficient associates R&D investment with technology transfer. An alternative interpretation of the interacted term indicates that countries lie far behind from the frontier conduct initially little R&D and thus marginal productivity of R&D at the early stages is quite high (Griffith et al. (2004)). This argument implies that R&D might be also subject to non-linearities.

Appendix 4 replicates benchmark specifications of table 2 by using a stock measure of R&D to check whether a stock measure is more informative and to check for possible non-linear relationship between R&D and TFP growth. The pattern revealed from a stock measure of R&D does not provide any change in the pattern of R&D indicating that estimates of table 2 in the previous section are robust to alternative measures of R&D. After controlling for a quadratic term of R&D share in columns (3) and (4), no differences arise from the previous specifications, suggesting that in Greek manufacturing industries R&D might not be subject to diminishing returns to scale.

The last test of robustness of the main results refers to the measure of the frontier. A crucial question is to what extent results are sensitive to a different definition of the frontier country? From tables 1 and 2 and the econometric analysis (Appendix 1) during the sample period Greek industries converge towards the TFP level of their German counterparts and at the last year of the sample Greece's productivity was very close to that of Germany (it is about 95%). This pattern is likely to indicate that as approaching the end of the period under study the potential of technology transfer becomes small since the gap between countries has almost closed. To check whether results are unaffected when productivity differences between the non-frontier and the frontier country remain meaningful even at the end of the period, France is used as an alternative measure of the frontier country (Appendix 5). To provide a close comparison with the results already obtained, specifications (2), (3) and (4) are replicated from table 2.

The TFPgap variable is always positive and statistically significant apart from the specification (4). However, the speed of adjustment when France is considered the frontier seems to be higher than it is with Germany. For example the coefficient of TFPgap in column 2 of table (2) is 3.5%, while now it is 5.6%. This result is reasonable taking into account that on average TFP differences between Greek and French industries are higher than those between Greek and German industries. Therefore, the potential of technology transfer is higher in the former case and hence the TFP growth rate is higher. Trade share maintains a negative sign likewise it does when Germany is the frontier country. The only difference emerges in this table is that the trade share is now statistically insignificant in all specifications. The same insignificant pattern applies for the interacted trade term. Interestingly enough, the R&D share turns up with a positive and statistically significant coefficient. This pattern is consistent throughout all the specification in table and it is the only important difference compared to estimates obtained for R&D shares when Germany is used as the frontier country. In the same line of argument, the second face of R&D appears now to be informative regarding its effect on growth of total factor productivity. This result suggests that the second face of R&D is not anymore present when the Frontier country is France while a positive and strong direct effect of R&D is documented at least in the within group estimator. This finding is not consistent with the suggestion of Acemuglu (2005) and Cameron (2005), who argue that the importance of R&D as a country falls far behind the frontier is to improve the country's absorptive capacity rather than to have a direct effect on productivity growth. The minimum to median wage ratio is always negative and statistically significant at conventional levels from estimations using the whole panel (columns (1) and (2)), while it remains negative but insignificant when the reduced panel is considered (columns (3) and (4)). As far the concentration variable is concerned it is appeared to be no informative concerning TFP growth; it has a positive sign in the within groups estimation and marginally significant at the 10% level while it turns up with a negative coefficient in the IV estimation. Overall, considering France as frontier country, results tend to be less significant about the other sources influence TFP growth. The main force drives TFP growth is captured within autonomous technological transfer and the contemporaneous term of French industries' TFP growth. This pattern is reasonable given the fact that at the end of the period, Greek industries yet fall behind compared to their French counterparts and thus the potential of technological transfer is still quite high.

6. Conclusion

The present study analyses the crucial issues of productivity performance, which is an vital issue strongly related with improvements of economic welfare. Productivity growth in the present chapter is analyzed under the general theme of TFP convergence, which has been a recently development in the research agenda of productivity analysis. The current study contributes to the TFP convergence literature by providing evidence from a non-frontier country, which is Greece and a frontier country, which is Germany. The empirical evidence refers exclusively to two European countries and this is something new in the literature since most of the empirical evidence so far compares TFP performance of a non-frontier country (still developed), with United states. In a more general view, this pure intra-European comparison, constitutes a central issue of the European economic integration, given that many policies seeks to narrow the gap between the core and peripheral countries of EU. Consequently, it is useful for the policy maker to be aware of the factors that stimulate productivity growth and thus to design the appropriate policy devices in order to promote productivity over time.

The results obtained from the present study regarding the sources affecting productivity refer exclusively to Greek manufacturing industries; however, more general lessons can be learned from the present analysis and be considered as compatible to other European countries that experience the same level of development and perhaps the same economic features with Greece. The first finding of the study is that there is a convergence process at work during the sample period. In the beginning of the period, on average the Greek manufacturing industries are 10 % productive as their German counterparts while at the end of the period Greek industries have almost close this gap. On average, Greek manufacturing industries experience faster rates of TFP growth indicating the well-defined argument that countries fall behind tend to grow faster. Examining more systematically the current evidence the econometric analysis in most specifications confirms that the higher is the TFP gap the faster the rate of TFP growth, while variables of special interest are the interacted terms of trade and R&D with TFP gap. Especially, the R&D interacted term maintains a positive and statistically significant pattern in almost all the specifications carried out in the chapter. This finding suggests that trade and R&D have no direct effect upon productivity but instead they stimulate growth in a more indirect way assisting the domestic industry to improve its absorptive capacity. This result indicates that the role of R&D should not be underestimated and clearly policies in favorable to firms that conduct substantial R&D effort should be in practice. On this basis, economic agents and entrepreneurs should be aware that a positive direct effect of R&D might not be always feasible, nonetheless even if you cannot produce new technological products, investment in R&D helps less developed countries to be effective users of technological products already developed abroad. In the same line of argument, trade exposure might not have direct effects but it is very likely to improve country's absorptive capacity. Benchmark specifications consistently reveal a negative coefficient of trade share contradicting to propositions of endogenous growth theory; such an empirical finding poses a crucial question regarding the precise relationship between trade and TFP growth. A sensitivity analysis shows weak evidence for the non-linear terms of import and export shares indicating that positive effects from learning by importing (or exporting) are not infinite. Instead, there is a critical point at which the knowledge potential has been exhausted and thus further exposure is not any more beneficial. In general, Greek industries seem to learn more from importing than exporting since in the preliminary specification of the paper, the import interacted term is always positive and statistically significant while the interacted exporting term is insignificant.

Two new variables are also added in the analysis reflecting the impact of domestic conditions on TFP growth. The ratio of minimum wage to median wage is consistently negative and in almost all the specifications is significant. The concentration index is insignificant but after controlling for potential endogeneity with TFP growth, the result tends to be compatible with the view that monopolistic practices in the market are not an obstacle for efficiency but dominant firms exploit economies of scale and thus industry's overall productivity growth is affected positively. The most interesting field for policy making implications can be derived from the variable of labour market rigidities. Before one states strong conclusions should be aware that the measure of this variable is incomplete, in a sense that it is likely to reflect very particular effects and thus more generalized conclusions might lead to mistaken interpretations. Given that in Greece the wage determination is based on the unionization of the labour market, the present negative impact of the associated variable on TFP growth indicates that trade unions experience strong bargaining power achieving collective wage agreements that in some industries correspond to actual wages above the competitive level. Certainly, this practice neglect financial resources from other activities concerning training of personnel, adjustment and use of new technological techniques etc. Further arguments should be also done but with some caution; the negative impact of the labour market variable might refer to a very strict employment, which does not allow employers to adjust their work force effectively and quickly. On this basis, inefficient firms remain as such for a long period of time, simply because the existing legislation does not provide them with the appropriate legal frame in adjusting their labour input in a way that leads to an efficient reallocation of resources. After all, the question emerged is what it should be an appropriate policy reform within the labour marker in order to stimulate productivity growth? An insightful discussion of this issue is beyond the scope of the paper but easing the stringency in Greek labour markets will certainly have a positive impact on TFP growth as already suggested in Scarpetta and Tressel (2002). In order to do so, legislation should give to firms the ability to hire the personnel needed from the external market without legal rigidity or structural changes should take place in the salary schemes to ensure equivalence between actual wages and productivity levels.

After this study, there are some issues remain unexplored and definitely need further investigation. Two paths for further research that are strongly related to the current work are to quantify the direct impact of foreign R&D on domestic TFP (Coe and Helpman (1995) and Kneller (2000)) and to asses whether the pattern (i.e. type of goods traded) of trade really matters for TFP growth. In addition to these, future research should address issues such as the impact of FDI and firm dynamics on TFP growth. Both of these factors can be conduits of various positive spillovers that boost productivity performance. The presence of multinational companies in the domestic market is a channel that can diffuse techniques and new ideas increasing thus the rate of TFP growth. Simultaneously, entries (exits) in (from) the market as well as factors that drive this type of movements constitute core issues of the current productivity research agenda (Scarpetta, Tressel (2006))[29].

[29] Another study is in progress investigates how various channels affect productivity growth paying special attention to exporting, entry and exit of firms and R&D investment.

Appendix 1

Total Factor Productivity

The main source of data used in calculating TFP is OECD-STAN. Variables used are Value added (VALU), Value added Volume (VALUK), Labour compensation of Employees (LABR),Employees (EMPE), Gross Foxed Capital Formation (GFCF), Gross fixed capital formation volume (GFCFK). Full data series for Greek industries are available only for the period 1995-2003. Prior to this period STAN reports data only for value added and labour compensation. Data for the remaining variable for the period 1980-1994 are taken by EU KLEMS project run by Groningen Growth and Development Centre (GGDC). Data for hours worked on each manufacturing sector are taken by GGDC 60-Industry database. OECD-STAN provided a full data series for Germany during the whole period, for years before 1990 data refer to West Germany. Missing values in GFCF and GFCFK for German industries for 2003 are filled with values taken from EU KLEMS- GGDC database.

Trade

Values of imports and exports for Greek manufacturing industries between 1995-2033 are provided by OECD-STAN (release 05), while date for the period 1980-1994 are taken by OECD-STAN (release 01). Trade share is the sum of imports an export over production in nominal values. Trade data are not deflated into real values due to lack of appropriate deflators.

Research and Development

Data for R&D expenditures and R&D personnel are taken from OECD (Main Science and Technology Indicators, releases: 13r2-13r3 and 16&17r2-16&17r3). Data series for both variables starts from 1981 and they have many missing within year intervals. To fill in missing values, the STATA routine interpolation function is used. This considers that R&D expenditure is a positive function of time. Raw data are in current Euro prices. Nominal values are deflated by an R&D price index, which is defined as: $PR = 0.5(VAI + WAI)$, where VAI is a value added industry specific deflator and WAI is a nominal manufacturing wage index, taken by International labour Organization (ILO). The above definition of R&D deflator is given by Coe and Helpman (1995) and implies that half R&D expenditures are labour costs. The level measure of R&D is a share of real R&D expenditure to real value added while a complementary measure is also considered referring to R&D stock since the main text for more details. Data on are obtained by

Human Capital

It is measured as the share of workers with tertiary education over the entire labour force. Data for educational enrolment by level and for labour force are taken by UNESCO.

Concentration Ratio

An ideal measure for industry's concentration is the Herfindahl-Hirschman index; however, its calculation requires specific information for the whole number of individual firms in each industry and such a dis-aggregate data set is very difficult to be obtained for Greek manufacturing firms. Following a methodology proposed by Schmalensee (1977) the concentration index is computed as:

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

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 firm population and group of largest firms in the industry (i.e. in the current case this is five) the above index is easily computable. Schmalensee (1977) considers Herfindahl-Hirschman index as the ideal measure and after comparing twelve possible surrogates concludes that, the above index is the second best alternative. Market Share of the top five firms in each industry is calculated using information of total assets in monetary values provided by ICAP. The latter is a private Business Information and Consulting company that reports financial data for Greek manufacturing firms. Data used in the present study are reported from the annual financial directory of Greek manufacturing Sector and they are only available from 1993 and onwards.

Appendix 2

To obtain a more formal test of convergence for each industry the methodology of Bernard and Durlauf (1995) and Bernard and Jones (1996 a) is followed. In the present framework a Greek industry *i* is said to converge towards its German counterpart *i* if the TFP gap (i.e. $TFPgap = \ln(A_{i,F,t}) - \ln(A_{i,j,t})$, i=1,...,$N$) variable is stationary. A test of stationarity is developed by Kwiatkowski et al.(1992) or KPSS for brevity. This test differs from the standard Dickey-Fuller and Perron unit root tests by having a direct null hypothesis of stationarity. The null hypothesis of the KPSS test is implemented for both trend and level stationarity. As it is appeared in both columns of the table below the null hypothesis of stationarity is accepted in all industries. Equivalently, this suggests that for all industries in the sample convergence is at work. The fact that it is possible to accept the null hypothesis in all industries indicates that data of the current study support the formulation of an equilibrium correction model (ECM) as specified in (10). The economic content of the observation is that for industries where TFP gap is not stationary, the long-run average productivity growth would be different (Bernard and Jones 19996a).

Unit Root Tests

Industry	Trend	Level
Food products, beverages and tobacco	0.154	0.391
Textiles, textile products, leather and footwear	0.157	0.391
Wood and products of wood and cork	0.148	0.394
Pulp, paper, paper products, printing and publishing	0.143	0.395
Coke, refined petroleum products and nuclear fuel	0.143	0.391
Chemicals and chemical products	0.15	0.386
Rubber and plastics products	0.148	0.392
Other nonmetallic mineral products	0.136	0.419
Basic metals	0.148	0.402
Fabricated metal products, except machinery and equipment	0.139	0.379
Machinery and equipment, n.e.c.	0.145	0.369
Electrical machinery and apparatus, nec	0.157	0.387
Radio, television and communication equipment	0.15	0.4
Medical, precision and optical instruments, watches and clocks	0.144	0.154
Other transport equipment	0.2	0.395
Manufacturing nec	0.158	0.396

Notes: 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 maximum lag order of the test is derived by a rule provided by Schwert (1989). The Schwert criterion for the current test chooses 8 as maximum lags for all industries.

Appendix 3 TFP Growth and Bounded Learning

	1982-2003 (1)	1982-2003 (2)	1982-2003 (3)	1982-2003 (4)	1982-2003 (5)	1982-2003 (6)	1982-2003 (7)
Estimation	Within Groups	Within Groups	IV	Within Groups	IV	Within Groups	Within Groups
$\Delta \log TFP_{i,F,t}$	0.097	0.092	0.088	0.095	0.089	0.07	0.06
	(1.35)	(1.29)	(1.12)	(1.31)	(1.28)	(0.85)	(0.77)
log TFPgap	0.045	0.041	0.004	0.045	0.009	0.013	0.012
	(4.03)***	(3.66)***	(0.12)	(4.19)***	-0.32	(0.72)	(0.74)
$\log(R\&D/VA)_{i,t-1}$	0	0	0.009	0.001	0.003	0.008	-0.002
	(0.02)	(0.03)	(0.5)	(0.11)	(0.21)	(1.45)	(0.32)
$(R\&D/VA)_{i,t-1} * TFPgap$	0.507	0.632	1.079	0.594	1.028	1.366	1.142
	(1.3)	(1.58)	(2.18)**	(1.52)	(2.42)**	(3.24)**	(2.68)**
$\log(Trade/X)^2{}_{i,t-1}$	0.014						
	(1.34)						
$(Trade/X)^2{}_{i,t-1}*TFPgap$	-0.001						
	(1.67)*						
$\log\left(\frac{MinWage}{MedianWage}\right)_{t-1}$	-0.054	-0.05	-0.101	-0.054	-0.101	-0.13	-0.144
	(1.86)*	(1.70)*	(1.99)**	(1.87)*	-1.6	(4.25)**	(4.77)**
$(IMP/X)^2{}_{i,t-1}$		0.008	-0.004				
		(1.70)*	(0.16)				
$(IMP/X)^2{}_{i,t-1} * TFPgap$		0	0				
		(1.35)	-0.69				
$(EXPG7/X)_{i,t-1}$							-0.006
							(0.74)
$(EXPG7/X)_{i,t-1} * TFPgap$							-0.081
							(1.01)
$(IMPG7/X)_{i,t-1}$						-0.028	
						(2.93)**	
$(IMPG7/X)_{i,t-1} * TFPgap$						0.007	
						(1.13)	

$\log(EXP/X)^2_{i,t-1}$				0.003	-0.004		
				(1.92)*	-0.15		
$(EXP/X)^2_{i,t-1}*TFPgap$				0	0		
				(1.04)	(1.12)		
R-squared	0.2039	0.22	0.05	0.215	0.09	0.26	0.24
Observations	321	321	278	321	278	231	231
Number of sector	16	16	16	16	16	16	16
z statistics in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%							
Diagnostic Tests							
Wald test; P-value	107.10 0.00	101.8 0.00	128.41 0.00	10133 0.00	166.53 0.00	53.56 0.00	49.24 0.00
Serial correlation; P-value			15.110 0.00		13.194 0.00		
Sargan Test; P-value			6.630 0.2496		8.358 0.1376		

NOTES: All variables are weighted by industry's value added in manufacturing sector at period 1982; Estimates in (1), (2), (4), (6), and (7) are based on a Fixed Effects within group estimator corrected for heteroscedasticity, cross-sectional correlation and industry specific serial correlation. Specifications in columns (4) and (5) are IV–FE estimations. Specifications in columns (2) and (4) are IV–FE estimations. Instruments are the same as in table 4.

Appendix 4 TFP Growth and R&D Stock

	1982-2003 **(1)** Within Group-Fixed Effects	**1982-2003** **(2)** IV	**1982-2003** **(3)** Within Group-Fixed Effects	**1982-2003** **(4)** IV
$\Delta \log TFP_{i,F,t}$	0.099	0.096	0.091	0.09
	(1.34)	(1.38)	(1.28)	(1.26)
log TFPgap	0.032	-0.048	0.014	-0.136
	(2.42)**	(1.24)	(0.54)	(1.71)*
$\log(Trade/X)_{i,t-1}$	-0.034	-0.111	-0.028	-0.129
	(2.75)***	(2.06)**	(2.27)**	(2.33)**
$(Trade/X)_{i,t-1}*TFPgap$	0.008	0.031	0.008	0.056
	(1.54)	(1.62)	(1.5)	(2.68)**
$\log(R\&Dstock/VA)_{i,t-1}$	-0.001	0.009		
	(0.21)	(0.37)		
$(R\&Dstock/VA)_{i,t-1}$ *TFPgap	0.144	0.217		
	(1.62)	(2.14)**		
(Min Wage/Median Wage)$_{t-1}$	-0.058	-0.145	-0.05	-0.112
	(1.91)*	(2.70)***	(1.75)	(2.36)**
$\log(R\&D/VA)^2_{i,t-1}$			-0.001	-0.004
			(1.71)	(2.07)**
$(R\&D/VA)^2_{i,t-1}$ *TFPgap			0.001	0.003
			(1.2)	(1.68)**
R-squared	0.1690	0.07	0.1826	0.02
Observations	313	280		278
Number of sectors	16	16		16
Diagnostic Tests				
Wald Statistic; P-value	82.96 0.00	157.49 0.00	115.00 0.00	154.43 0.00

Serial Correlation-value		14.443 0.0017		25.38 0.0001
	1982-2003 (1)	1982-2003 (2)	1993-2003 (3)	1993-2003 (4)
Sargan Test for the validity of Instruments; P-value		7.159/0.209 1		8.678/0.122 6

NOTES: All variables are weighted by industry's value added in manufacturing sector at period 1982; Estimates in (1), (3) are based on a Fixed Effects within group estimator corrected for heteroscedasticity, cross-sectional correlation and industry specific serial correlation. Specifications in columns (2) and (4) are IV–FE estimations. The endogenous variables are TFPgap, $\log(Trade/X)_{i,t-1}$ and $(Trade/X)_{i,t-1}*TFPgap$; as instruments are used their lags in third and fourth order plus third and fourth lags of $\log(R\&D/VA)_{i,t-1}$. The serial correlation test is based on Wooldridge (2002); the null hypothesis is no serial correlation. The Sargan test is a statistic for the validity of instruments following the Chi-squared distribution; in the current model, n equals to 5 and clearly suggest accepting the null hypothesis that the instruments are valid.

Appendix 5 Benchmark Specifications with France as Frontier Economy

	Within groups	IV	Within groups	IV
$\Delta \log TFP_{i,F,t}$	0.277	0.006	0.19	0.404
	(3.47)***	(0.17)	(2.10)**	(2.28)**
log TFPgap	0.056	0.251	0.1	0.097
	(5.43)***	(2.52)**	(3.27)***	(0.35)
$\log(Trade/X)_{i,t-1}$	-0.005	-0.062	-0.027	0.076
	(0.4)	(1.26)	(1.43)	(0.23)
$(Trade/X)_{i,t-1}*TFPgap$	-0.006	0.024	0.004	0.184
	(1.26)	(1.3)	(0.38)	(1.05)
$\log(R\&D/VA)_{i,t-1}$	0.011	0.02	0.014	0.085
	(2.07)**	(1.36)	(2.00)*	(1.38)
$(R\&D/VA)_{i,t-1}$ *TFPgap	0.461	0.373	0.44	-2.018
	(1.08)	(0.93)	(1.09)	(1.61)
(Min Wage/Median Wage)$_{t-1}$	-0.046	-0.084	-0.057	-0.217
	(1.98)**	(1.78)	(0.97)	(1.33)
$\log CR_{i,t-1}$			0.024	-0.434
			(1.66)*	(1.35)
R-squared	0.1520	0.1124	0.1548	0.04
Observations	307	267	153	122
Number of sectors	16	16	16	16

Absolute z statistics in parentheses * significant at 10%; ** significant at 5%;***significant 1%

Diagnostic Tests				
Wald test; P-value	212.21	169.09	37.75	42.85
Serial Correlation; P-value		15.925 0.0012		8.406 0.01
Sargan Test ; P-value		5.163 0.3963		2.265 0.89

Notes: All observations are weighted by industry's value added in manufacturing sector at period 1982; Estimates in columns (1), (3) are based on a Fixed Effects within group estimator corrected for heteroscedasticity, cross-sectional correlation and industry specific serial correlation. Specifications in columns (2) and (4) are IV–FE estimations. Instruments are the same as in table 4.

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INVESTMENT DECISIONS AND CAPITAL ADJUSTMENT COSTS: ESTIMATION OF A DYNAMIC DISCRETE CHOICE MODEL USING PANEL DATA FOR GREEK MANUFACTURING FIRMS

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Abstract

In this paper we estimate a dynamic structural model of capital investment at the firm level. Our dataset consists of a balanced panel of 1419 Greek firms. Two important features are present in our dataset. There are periods in which firms decide not to invest and periods of large investment episodes. This empirical evidence of infrequent and lumpy investment is in favour of irreversibilities and non-convex capital adjustment costs. Following Cooper and Haltiwanger (2006) we consider a dynamic discrete choice model of a general specification of adjustment costs including convex and non-convex components. We also assume total irreversibility of investment. We use an indirect inference procedure as in Gourieroux, Monfort and Renault (1993) and Smith (1993) to estimate the structural parameters. Our goal is to investigate the nature of the capital adjustment process at the firm level for Greek data.

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1. Introduction

1.1. Motivation

Investment is very important to macroeconomics. As one of the main components of aggregate demand, investment plays a central role in both the cyclical and long run performance of any economy. Economists have long been trying to understand the components of investment activity and much effort has been dedicated to this direction. Although a voluminous literature concerning investment at macro level exists, it has been in the last years when investment literature had shown an increasing concern about the modeling of investment decisions at micro level.

The neoclassical theory and Tobin's Q theory with strictly convex adjustment costs have been the workhorse of modern investment research. The Jorgenson's (1963) neoclassical model –with no capital adjustment costs- yielded a static decision rule for capital stock. Jorgenson's approach compares the marginal product of capital with its *user cost*. The optimal level of capital stock results from the equivalence between the marginal product of capital and the *user cost* of capital. Tobin's (1969) approach compares the capitalized value of marginal investment with the replacement cost of one unit of capital. The capitalized value of marginal investment is the market value of one unit of capital.[1] The ratio of the market value of one unit of capital to its replacement cost is called Tobin's q and conditions the decision of undertaking or not an investment project.[2] Empirical evidence has shown the failure of these models to explain investment behavior. The estimates of investment responsiveness to fundamentals have been very low.

For analytical and econometric convenience, the literature adopted a quadratic-strictly convex function for the adjustment costs. Strictly convex adjustment costs imply that it is always optimal to make a continuous, non-zero adjustment (there are no periods of time with zero adjustment). This feature is strongly at odds with data on investment. Empirical research reveals that firms tend to concentrate the adjustment of capital in relatively short periods of time, which alternate periods of no adjustment. In other words, the adjustment process of capital can be characterized as intermittent

[1] Keynes (1936, p. 151) early noted that the incentive for creation of new capital depends on the ratio of capital market value to the cost of creating new capital.
[2] See Tobin (1969), Lucas and Prescott (1971), Mussa (1977), Hayashi (1982) and Abel (1983) for seminal contributions as well as Abel (1990) for a review and link to Jorgenson's (1963) model.

and lumpy. The assumption of strictly convex adjustment costs and the resulting linear dynamic models are unable to explain the infrequent and lumpy dynamic pattern of investment activity.

Doms and Dune (1998) using data for 12000 US manufacturing firms, for the period 1972-1989, find that over the half of the firms increase their capital stock more than 35 percent in a single year. Anti Nielsen and Schiantarelli (2003) report similar findings for Norwegian firms' panel data. They note that, in every year, about 30 percent of the firms undertake no investment at all, at disaggregate level.[3]

The above evidence of intermittent and lumpy adjustment of capital can be supported by non-convex adjustment cost function. One way of explaining the periods of no adjustment is the inclusion of a linear (piecewise) adjustment cost to the model. Zero adjustment (inactivity) entails non-differentiability and in general, the linear adjustment cost component is interpreted as the reflection of the (partially) irreversible nature of investment. Total irreversibility means that gross investment cannot be negative. Partial irreversibility appears when the sale price of capital is lower than its replacement cost. Although linear adjustment cost explains the infrequent adjustment of capital, it cannot suitably explain the lumpiness.

To capture the lumpy character of adjustment, Hamermesh (1989) first proposed the introduction of a fixed component in the adjustment costs function. Incorporating this non-convexity, a firm decides whether to invest in capital or not. This decision depends on whether the expected gains of the investment are high enough to overcome the fixed costs. If fixed costs are substantial, firm will invest infrequently, and when it does, it will carry out a large investment.

Abel and Eberly (1994) extend the Q model incorporating quadratic, piecewise and fixed adjustment costs in their model. They show that for critical values of marginal q three potential regimes for investment occur: positive, zero and negative gross investment. In an empirical application of this model, Barnett and Sakellaris (1998) and Abel and Eberly (2002) reach the conclusion that non-linearities are important in explaining investment behavior.

Caballero, Engel and Haltiwanger (1995) and Caballero and Engel (1998, 1999) consider the gap between actual and desired capital stock to be the fundamental of investment, in order to interpret the non-linearities in the investment process. They

[3] In aggregate level this percentage goes down at 6 percent.

implement the *adjustment hazard* function. This function is defined as the difference between the log of actual and the log of desired level of capital, where the latter is the optimum level of capital obtained under zero adjustment costs. The model predicts that the larger the gap is, the higher the probability of investment to be recorded is.

Cooper and Willis (2001) criticize the "gap methodology" arguing that the results are particularly sensitive to mis-specification of the target level to which the actual capital stock is assumed to adjust.

Cooper and Haltiwanger (1993) and Cooper, Haltiwanger and Power (1999) investigate the machine replacement problem in the presence of non-convex adjustment costs. They find that, however low the level of current capital stock is (thus, the older the capital is), the higher the probability of investment to occur is. Furthermore, the longer you wait for the replacement of capital, the larger the adjustment of capital will be.

Cooper and Haltiwanger (2006), in their influential work, compare models with alternative adjustment costs: quadratic, fixed adjustment costs and adjustment costs associated with irreversibility of investment. They show that the models with only one type of adjustment cost are not successful in matching the dynamic nature of investment. On the other hand, the mixed model of non-convex and convex costs of adjustment matches satisfactorily the features of investment. In order to estimate the structural parameters of the model, Cooper and Haltiwanger use the simulated method of moments so as to match key moments of the plant level capital adjustment dynamics.[4]

Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2005) extend Cooper and Haltiwanger's (2006) model incorporating the existence of financial market imperfections.[5]

1.2. Our work

Our approach specifies a dynamic structural model of investment at the firm level in order to get a better understanding of microeconomic investment decisions and the nature of capital adjustment costs Greek firms face when they decide to undertake an investment project. The aim of this paper is to investigate the effects of

[4] See also Cooper and Ejarque (2001).

[5] Lapatinas (2005) provides a detailed review of investment models and numerous references to the motivation and results of that lengthy literature.

both convex and non-convex adjustment costs of capital on Greek firms' investment activity. Moreover its target is to look into the dynamic nature of capital adjustment process at the firm level. In addition to this, we monitor if the Greek micro data supports the presence of both convex and non-convex components of adjustment costs and more specifically to find the structural estimates of the convex and non-convex adjustment costs that are consistent with the micro evidence for the Greek economy. Our work, as far as we know, constitutes the first attempt of studying the investment behavior of Greek economy at micro level. As a result, we hope that this work not only contributes to the better understanding of the complex dynamics of investment, but it also constitutes an essential tool for the evaluation of different policies regarding Greek economy.

In this paper a dynamic structural model of capital investment at the firm level is estimated. We inquire about the investment behavior of a balanced panel of 1419 Greek firms (9933 observations) for the period 1996-2002. The evidence of infrequent and lumpy investment is present in our dataset. Based on these empirical facts, we introduce a dynamic discrete choice model with a general specification of adjustment costs including both convex and non-convex components. We also assume total irreversibility of investment. We use an indirect inference procedure as in Gourieroux, Monfort and Renault (1993) and Smith (1993), in order to estimate the structural parameters of the model.[6] The structural parameters determining the magnitude of convex and non-convex adjustment costs are chosen to reproduce the econometric relationship between the investment rate and the profitability shocks with their square term. The square term of profitability shocks captures the non-linearities in the investment process.

The rest of the paper is organized as follows. In section 2 we describe the dataset used in this study. Section 3 formulates the dynamic structural model of investment. In section 4 we describe the estimation of the model: the methodology (section 4.1), the estimation method we implement (section 4.2) and the estimation results (section 4.3). Section 5 gives the main policy and modeling implications of our findings and section 6 concludes.

[6] The reason for not using analytical tools is the presence of non-convex adjustment costs that cause the dynamic problem to be discontinuous. Firms need to choose between undertaking or not an investment project.

2. Features of Actual Data

Data Set

The main data source in this paper is the ICAP firm-level database. The ICAP is the largest company providing economic data and consultative services in Greece and is a member of the international network INFOALLIANCE and participant of the European economic and business information network EUROGATE. The company is also a member of Federation of Business Information Services (FEBIS), European Association of Directory and Database Publishers (EADP), European Federation of Management Consulting Association and a member of the international research organization GALLUP INTERNATIONAL. Our data are a balanced panel of 2097 active Greek manufacturing firms over the period 1996-2002 containing 14679 observations. These are the data we get after filtering all the manufacturing firms that are registered in the ICAP databank, depending on the availability of the plant, property and equipment data. We delete firms with missing data points between 1996 and 2002. Since net profits are an essential variable to our analysis, we only keep manufacturing firms that have positive profits information. This leads to 1690 firms on 11830 observations.

The definition of capital includes plant, property, and equipment. ICAP provides fixed assets items for each firm which represent the book value of all fixed assets of the firm, including building, land and structures, machinery and equipment, intangible fixed assets and financial fixed assets such as share ownership in other companies. For this paper, the book value of the capital stock, $p_t K_t$ counts land and estates, buildings and structures, and machinery and equipments.[7] Our investment measure, $p_t I_t$, is calculated by applying a perpetual inventory procedure with a depreciation of 8 percent per annum for all years[8]:

$$p_{t+1}K_{t+1} = p_t I_t + p_t K_t(1-\delta_t) \Rightarrow p_t I_t = p_{t+1}K_{t+1} - p_t K_t(1-\delta_t) \tag{1}$$

Real investment, I_t, is constructed as investment at current prices, $p_t I_t$, deflated by the investment price deflator, with 1995 to be the base year. Real capital stock, K_t, is

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[7] For more details on sample selection see the Appendix

[8] This value is proposed by previous studies at micro-level, see for example Bond *et al.* (1999).

constructed in the same way. The investment rate is then defined as the ratio of real investment to the real capital stock, $\frac{I_t}{K_t}$.

The dataset of 1622 firms on 11354 observations is not our final dataset. Following Bayraktar, Sakellaris and Vermeulen (2005), we assume that investment rates higher than 90 percent are measuring a merger or acquisition. All the firms that display investment rate over 90 percent in any year among the period 1996-2002 are excluded from our panel. This leads to our final panel dataset of 1419 firms on 9933 observations for the period 1996-2002. The dataset is balanced and each firm has exactly 7 observations (6 observations for investment). The 1419 manufacturing firms comprise a considerable portion of the active Greek manufacturing firms. For the year 2000 the 1419 firms of our dataset represent about 6.6 percent of the private investment in Greece. They had a total investment expenditure of 1.26 billion euros, where the total private fixed investment (excluding stockbuilding) in Greece was 19 billion euros in 2000 (this is taken from the OECD data source).

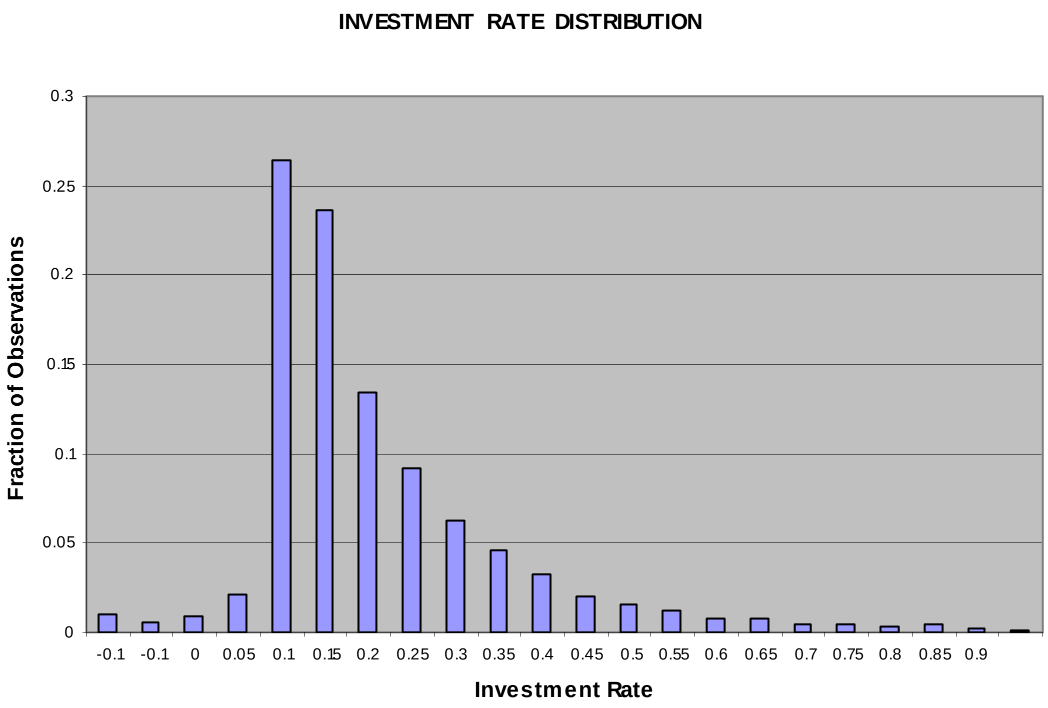

Figure 1: Investment rate distribution

Summary Statistics

Table 1 shows summary statistics of the data, Table 2 shows some features of the investment rate and Figure 1 represents the distribution function of the investment rate for the period 1996-2001.

Table 1. Summary statistics

	Mean	median	std. dev	min	max
I_{it}/K_{it}	0.18	0.14	0.16	-0.92	0.92
K_{it}	3.8	0.8	22.4	0	719

Note: capital stock is in million euros measured in 1995 prices

Table 2. Features of the distribution of the investment rate

Variable	Fraction of obs.
$\lvert I_{it}/K_{it}\rvert < 0.01$	0.55%
$\lvert I_{it}/K_{it}\rvert < 0.02$ (inaction region)	1.04%
$I_{it}/K_{it} < 0$	2.5%
$I_{it}/K_{it} > 0.2$ (positive investment spike)	31.7%
$I_{it}/K_{it} < -0.2$ (negative investment spike)	0.6%
$I_{it}/K_{it} < -0.02$	2.02%
corr($(I/K)_{it}, (I/K)_{it-1}$)	0.17

Note: all statistics are calculated for 1419 firms and for the period 1996-2002

All statistics are calculated by pooling data for 1419 Greek manufacturing firms and for the period of 1996-2002. In that period, the median firm had a capital stock of 0.8 million euros (in 1995 prices) and an investment rate at 0.14. The average value of the capital stock is 3.8 million euros and the average value of the investment rate is 0.18. The statistics of the investment rate are quite close to the statistics found by Cooper and Haltiwanger (2006), Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2005).[9] The first order autocorrelation of investment rate is 0.17. It is a quite large number when it is compared to 0.058 and 0.008, which are found by Cooper and Haltiwanger and Bayraktar, Sakellaris and Vermeulen respectively, and it is about the

[9] Cooper and Haltiwanger (2006), Bayraktar (2002), Bayraktar, Sakellaris and Vermeulen (2005) report a mean investment rate of around 12.2 percent, 12 percent and 19 percent respectively.

same with that found by Bayraktar. The inaction region is defined as less than 2 percent investment rate in absolute value. The fraction of observations in this region is 1.04 percent. Around 2.5 percent of the investment rates are negative (as a comparison it is 1.8 percent in Cooper and Haltiwanger, 8.68 percent in Bayraktar, and 4.7 percent in Bayraktar, Sakellaris and Vermeulen). This number is crucial as it concerns the structure of our model. The small fraction of negative investment rates comprises the basic motivation of considering investment, total irreversible –and not partial irreversible- in our model. In contrast with other studies, our formulation emphasizes the feature that a firm has only two options, of investing and not investing, and not a third one of selling capital (disinvesting). The investment rate is more than 20 percent for 31.7 percent of observations (positive investment spike). The latter number is 18.6 percent in Cooper and Haltiwanger, 17.34 percent in Bayraktar and 38 percent in Bayraktar, Sakellaris and Vermeulen. The fraction of observations that corresponds to investment rate less than -20 percent (negative investment spike) is only 0.6 percent. The presence of huge asymmetries between positive and negative investment is apparent in our dataset, since the last fraction is compared very low to the fraction of investment rate points that exceed 20 percent.

There is a huge empirical literature highlighting the importance of inaction and lumpiness in microeconomic investment datasets. Doms and Dune (1998) use data on American firms from 1972 to 1989. They find that more than half of them increase their capital stock over than 35 percent in some of the years considered. Anti Nielsen and Schiantarelli (2003), using information on Norwegian plants, find that about 30 percent of them present zero investment in an average year. Similar findings are reported concerning different countries in Barnett and Sakellaris (1998), Caballero, Engel, and Haltiwanger (1995), Abel and Eberly (2002), Eberly (1997).

The empirical evidence reported in this section stresses two important stylized facts: there are periods in which firms decide not to invest (periods of inaction) and periods of large investment episodes (lumpiness). These empirical findings clearly back up the adoption of an investment model which accounts for irreversibilities and nonconvex capital adjustment costs.

3. Model and Implications

The specifications of the model are from Cooper and Haltiwanger (2006). We assume a large and fixed number of firms. Firm i begins to period t with the inherited real capital stock, K_{it}, which has been adjusted in the previous period. Before making any investment decision, the firm observes the current period profitability shock. Given this state variable, the firm makes a decision on investment, depending on the nature of adjustment costs. The most general specification of the dynamic optimization problem of the firm is given by:

$$V(A_{it}, K_{it}) = \max_{\{I_{it}\}} \Pi(A_{it}, K_{it}) - C(I_{it}, K_{it}) - pI_{it} + \beta E_{A_{it+1}/A_{it}} V(A_{it+1}, K_{it+1}) \tag{2}$$

subject to the following constraint:

$$I_{it} = K_{it+1} - (1-\delta)K_{it} \tag{3}$$

where the profit function $\Pi(A_{it}, K_{it})$ is parameterized in the following way:

$$\Pi(A_{it}, K_{it}) = A_{it} K_{it}^{\ \theta} \tag{4}$$

where $0 < \theta < 1$, is the parameter for the curvature of the profit function. A_{it} is the current period profitability shock that contains both an idiosyncratic component, as well as an aggregate one. It is assumed that capital is the only quasi-fixed factor of production and all variable factors have already been maximized out of the problem. p is the constant cost of capital. δ is the depreciation rate of capital, which is constant too. The costs of adjustment are given by the function $C(I_{it}, K_{it})$. I_{it} is the level of investment that the firm's manager chooses. The function $C(I_{it}, K_{it})$ is general enough to have components of both convex and nonconvex costs of adjustment. The discount factor, β, is fixed and equals $(1+r)^{-1}$, where r is the risk-free market interest rate.

3.1. Adjustment Cost Structures

Much attention has been given in investment literature to the adjustment costs component. As Hamermesh and Pfann (1996) mention, this component was introduced into investment models so as to provide an explanation for the observation that firms change their demand for capital more slowly than the shocks to capital demand warrant.[10] Adjustment cost functions are not empirically observable. However, simulation results provide a better clue as to how different functional forms for adjustment costs imply different adjustment patterns. Therefore, as suggested by e.g. Cooper and Haltiwanger (2006) and Abel and Eberly (1994, 2002), attention is given to the estimation of a unified model that incorporates different types of adjustment costs. The adjustment cost functions incorporate both convex and nonconvex adjustment costs.

Convex Capital Adjustment Costs

Traditionally, a symmetric convex adjustment cost function is assumed, usually quadratic, like:

$$C(I_{it}, K_{it}) = \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it} \tag{5}$$

This is the standard specification in the literature. The parameter γ affects the magnitude of total and marginal adjustment costs. The higher the γ is, the higher the marginal cost of investing is and thus the lower the responsiveness of investment to variations in the underlying profitability of capital is. The maintenance and gradual capital adjustments can be considered as examples of convex adjustment costs. Given this adjustment cost function and the assumption of a constant factor price p, the first order condition of the dynamic optimization problem (2) produces the following equality between the marginal benefit of investment and its marginal cost:

$$\gamma I_{it} + p = \beta E_{A_{it+1}/A_{it}} V_{K_{it+1}}(A_{it+1}, K_{it+1}) \tag{6}$$

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[10] Hamermesh and Pfann (1996) present a survey on different adjustment cost models.

where $V_{K_{it+1}}(A_{it+1}, K_{it+1})$ is the derivative of the value function with respect to capital. In fact, this derivative is not observable. The conditional expectation in (6) is the marginal q of the Q theory. It represents the marginal value of an additional unit of future capital.[11]

The convex adjustment cost function implies that the investment rate is a linear function of the fundamentals. This suggests continuous investment activity.

Non Convex Capital Adjustment Costs and Total Irreversibility

Convex capital adjustment costs cannot match the findings of recent empirical studies for lumpiness of investment adjustment. Firms tend to concentrate their capital adjustment into short periods of time. Consequently, firms exhibit frequent periods of no adjustment (inaction). Therefore, it has been suggested to add fixed costs and irreversibility components to the adjustment cost function. Here, we allow the case of a component of costs being fixed when investment is undertaken regardless of the investment's magnitude. In order for this cost to be relevant at all stages of a firm's life we assume that it is proportional to firm's size as measured by its capital stock: FK_{it}. The structural parameter F determines the magnitude of fixed costs. The fixed adjustment costs represent plant restructuring, worker retraining and organizational restructuring. Generally, these costs capture indivisibility in capital and increasing returns to the installation of capital. We should emphasize that when there are no fixed costs associated with capital adjustment, the value function is continuous and concave. The introduction of fixed adjustment costs breaks the concavity.[12] [13]

In a model of total irreversible investment, the firm should decide on making investment or not.[14] While deciding regarding this issue, the firm compares the value

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[11] This term is unobservable, so equation (6) cannot serve for estimation. However, Hayashi (1982) shows, that under the additional assumption of proportionality of profits to the capital stock ($\theta = 1$), the problem of marginal q being unobserved can be overcome. Under the given assumptions, marginal q equals average q (Tobin's q) which in turn can be determined –at least for publicly traded firms- from stock market information. Of course, given that the estimate of the curvature of the profit function is significantly less than 1, any Q theory is misspecified.

[12] Slade (1998) and Aguirregabiria (1999) characterize the optimal decision rule for problems with nonconcave value functions.

[13] The role of fixed costs was stressed by Abel and Eberly (1994, 2002), Caballero and Leahy (1996), Caballero and Engel (1999) among others.

[14] Partial irreversibility allows a wedge between the selling and buying prices of capital. Total irreversibility does not allow capital to be sailed in a second-hand market. Firms cannot recover any investment cost.

function in case of capital adjustment (V^{a}) to the value function in case of non-adjustment (V^{na}), and chooses the maximum:

$$V(A_{it},K_{it}) = \max\left\{V^{a}(A_{it},K_{it}), V^{na}(A_{it},K_{it})\right\} \tag{7}$$

This formulation, occuring from the assumption of total irreversibility, emphasizes the feature that a firm has two options.[15] The dynamic optimization problem in the case of capital adjustment is:

$$V^{a}(A_{it},K_{it}) = \max_{\{I_{it}\}} \Pi(A_{it},K_{it}) - C(I_{it},K_{it}) - pI_{it} + \beta E_{A_{it+1}/A_{it}} V(A_{it+1},K_{it+1}) \tag{7a}$$

subject to the constraint

$$I_{it} = K_{it+1} - (1-\delta)K_{it}$$

The value function in the case of no adjustment, on the other hand, is defined as follows:

$$V^{na}(A_{it},K_{it}) = \Pi(A_{it},K_{it}) + \beta E_{A_{it+1}/A_{it}} V(A_{it+1},(1-\delta)K_{it}) \tag{7b}$$

In this framework, there will be periods of inaction when fundamentals are not favorable and periods of bursts of investment when fundamentals are high or low enough. The firm invests when its capital stock is less than its optimal level, otherwise prefers to avoid adjustment costs and remains inactive.

3.2. Value Maximization

The firm manager's dynamic program can be written as follows:

$$V(A_{it},K_{it}) = \max\left\{V^{a}(A_{it},K_{it}), V^{na}(A_{it},K_{it})\right\} \tag{8}$$

[15] If we had assumed partial irreversibility, also a third alternative option of selling capital would have been occurred.

The manager needs to choose optimally between investing (adjusting capital), with value $V^a(.)$, or undertaking no investment at all, with value $V^{na}(.)$. Both of these two alternative options have a value, given by:

$$V^a(A_{it},K_{it}) = \max_{\{I_{it}\}} \Pi(A_{it},K_{it}) - \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it} - FK_{it} - I_{it} + \beta E_{A_{it+1}/A_{it}} V(A_{it+1},K_{it+1})$$

(8a)

subject to the constraint $I_{it} = K_{it+1} - (1-\delta)K_{it}$

$$V^{na}(A_{it},K_{it}) = \Pi(A_{it},K_{it}) + \beta E_{A_{it+1}/A_{it}} V(A_{it+1},(1-\delta)K_{it}) \tag{8b}$$

In more detail, the value of investment given by (8a) implies that investing (buying capital) incurs two sources of costs. The first is the investment outlay, I_{it}, in which the cost of capital is normalized to one. The second is the adjustment cost, which in turn has a fixed and a convex component. The value of investment is defined as the profits minus total costs under the optimal decision, plus the discounted future value, given this period's decision and optimal behaviour in subsequent periods. Equation (8b) gives the value of no adjustment (inaction), which of course does not involve any costs or maximization.

Due to the presence of nonconvexities, which cause discontinuity in the investment process, the model cannot be solved analytically. The model is solved using a numerical method known as the Value Function Iteration method. This method can be summarized as follows. Let V be the value function. The value function iteration starts with some initial value V_0 and then evaluates $V_{j+1} = T(V_j)$ for $j = 0,1,2.....$ (where T is a mapping operator). The desired value function is obtained when the difference between V_{j+1} and V_j is less than some predetermined threshold value.[16]

[16] See Rust (1987a, b) for details.

The set of the structural parameters is given as $\{\beta, \delta, \theta, \gamma, F\}$. These together with the transition matrix for the profitability shocks determine the behavior of the model.

4. Estimation of the Model

4.1. Methodology

4.1.1. Estimation of the profit function

The profit function is given by

$$\Pi(A_{it}, K_{it}) = AK_{it}^{\theta}$$

where A_{it} is the profitability shock, θ is the curvature of the profit function and K_{it} is the firm level capital stock. In this model, it is assumed that capital is the only quasi-fixed factor of production and all the variable factors have already been maximized out of the problem. We estimate θ by regressing the natural log of net profit (net of cost of production) on the natural log of the replacement value of the capital stock using firm level Greek panel data. Although θ is assumed to be the same for each firm at each period, we remove fixed effects in order to take into account the structural differences across firms (in order to fix the structural heterogeneity problem)[17]. If θ is less than one, this shows the decreasing marginal profitability of capital. This might be caused by some degree of monopoly power or decreasing returns in the technology. From our data θ is estimated as 0.7, with a standard error of 0.006. This estimate of θ is not at variance with other estimates in the literature. Cooper and Ejarque (2001) find the same estimation in their work and a curvature of between 0.5 and 0.8 is estimated by Gilchrist and Himmelberg (1999).

4.1.2. The Fundamental of Investment: Profitability Shocks

The investment literature is traditionally relied on neoclassical Tobin's q. Tobin's q is equal to the ratio of the market value of firms to the replacement value of capital. The neoclassical models that take Tobin's q as the fundamental of investment

[17] We remove fixed effects by presenting profits and capital as deviated from the firm-level mean.

are too simple to explain complex dynamics of investment and rely on very strict assumptions of perfectly competitive product markets and quadratic convex adjustment costs. The quadratic convex capital adjustment costs imply a linear relationship between the investment rate and Tobin's q, therefore neoclassical investment models deal only with the smooth part of the capital adjustment process. In recent years, this feature is strongly at odds with the empirical studies which reveal that at the micro level, firms tend to concentrate the adjustment of capital in relatively short periods of time, pointing the lumpy, infrequent and sunk nature of investment. These facts have stimulated the introduction of new empirical fundamentals in order to explain investment behaviour.

Caballero and Engel (1999) introduce the gap between the desired and actual capital stock, which, until today, is the most commonly used fundamental of investment in the studies. In their model, once the gap reaches a threshold level, the adjustment process starts at once. The empirical investigation of this fundamental by Caballero, Engel and Haltiwanger (1995) shows that the response of investment to the gap is nonlinear, supporting therefore the existence of non convex adjustment costs. In parallel with the development of the literature arguing that non convexities and irreversibilities play a central role in investment, a literature relating the empirical failure of the neoclassical model to possible measurement errors in Tobin's q evolved. This literature focuses on correcting possible mismeasurement of Tobin's q in order to explain the inadequate results of the "traditional" literature.[18] [19] The idea behind is that the presence of measurement errors prompts fundamentals to be insufficient determinants of investment. Since the main indicator of firms' investment opportunities is expected profitability and since it is not easy to be directly calculated, it is generally approximated by current profitability measures. Abel and Blanchard (1986) first proposed present value of marginal revenue flows of capital to be one of these measures and Gilchrist and Himmelberg (1995, 1999) constructed this "*Fundamental Q*" measure pooling U.S firm level data. The last and most recently worked up alternative fundamental of investment is profitability shocks. Profitability

[18] See Cummins, Hasset, and Oliner (1999) and Gilchrist and Himmelberg (1995, 1999)

[19] Hayashi (1982) and Abel (1979) show that the neoclassical model with convex adjustment costs yields the marginal q value. Since marginal q is unobservable to the econometrician, marginal q can be approximated by the average value of q, under the strict assumptions of linear homogeneous net revenue function and perfectly competitive markets. The use of average q as a proxy measure of marginal q might be subject to measurement errors.

shocks are defined as changes in firms' profits that cannot be attributed to changes in their factors of production.

4.1.3. Calculation of the profit shocks

There are two alternative ways of calculating the profitability shocks, A_{it}. The first way calculates A_{it} indirectly through the first order condition for profit maximization with respect to employment. The second way of calculating A_{it} is through regressing profits on capital, and taking the residuals. Cooper and Haltiwanger (2006), Bayraktar (2002), Bayraktar, Sakellaris and Vermeulen (2006) use the first way because the standard deviation of the shocks using this way is low compared to the standard deviation calculated using the second way. Low standard deviation of the shocks causes the transition matrix to be more informative. Although we fully appreciate the fact that using profit data instead of employment data might raise measurement errors, since employment data is not available we compromise on the second way. We regress the log of profits on the log of capital including time dummies, after removing the fixed effects, and the residuals of this regression represent the idiosyncratic profitability shocks, a_{it} (i denotes the firm and t the period) [20]. Table 3 shows some features of the idiosyncratic profitability shocks.

Table 3. Features of the idiosyncratic profitability shocks, a_{it}

minimum:	-0.72
maximum:	0.34
std. dev.:	0.1
autocorrelation:	0.693

4.1.4. The relationship between investment and profitability shocks

Throughout this paper we study the following relationship between investment and profitability shocks

$$\tilde{i}_{it} = \Psi_0 + \Psi_1 a_{it} + \Psi_2 (a_{it})^2 + u_{it}$$

[20] Since we remove fixed effects, include time dummies, and the variables are taken in log form, the residual shocks are the firm specific idiosyncratic shocks in log form (time dummies capture the aggregate component of the profitability shocks).

where $\tilde{i}_{it}$ is the deviation of the investment rate of firm i in period t from the firm specific mean, a_{it} is the idiosyncratic profitability shock, $(a_{it})^2$ is the square term of a_{it}. The square term is included in order to test for our dataset the argument that the investment process is a non-linear function of the fundamentals.

Table 4. Summary Statistics of the regression variables

	mean	std. dev	min	max
$\tilde{i}_{it}$	0.00	0.154	-1.07	0.7
a_{it}	0.00	0.1	-0.72	0.34
$(a_{it})^2$	0.01	0.02	0.00	0.52

Table 5. Correlation matrix of the regression variables

	$\tilde{i}_{it}$	a_{it}	$(a_{it})^2$
$\tilde{i}_{it}$	1		
a_{it}	0.187	1	
$(a_{it})^2$	-0.016	-0.376	1

Table 6. Actual Data: Regression Results

Coefficients	**Estimated values**
a_{it}	0.322* (0.017)
$(a_{it})^2$	0.443* (0.08)

* significant at the 1 percent level. Rsquared adjusted = 0.04

Note: data was pooled for 1419 Greek firms and for the period 1996-2002. The estimation technique is the least square. The dependent variable is the deviation of the investment rate from the firm specific mean. Standard errors are reported in the parentheses.

Table 4 shows some summary statistics of the regression variables. Table 5 gives the correlation matrix of the regression variables. Notice that the investment rate is positively correlated with the contemporaneous profitability shock (correlation = 0.187). The least square estimated coefficients are reported in Table 6. The regression results show that both the level and the square term of the profitability shocks are important in explaining investment. Thus, we could say that these results support the argument of non-linear response of investment to its fundamentals.

4.1.5. Simulations

The coefficients $\{\beta, \delta, \theta\}$ and the profitability shocks are calibrated using the ICAP Greek firm-level database. We fix the discount factor β at the empirically reasonable value 0.97.[21] We have also estimated the model with different values of β (0.95 and 0.99) obtaining similar results. Following the relevant micro-level studies we pin down the depreciation rate, δ, at 0.08. The curvature of the profit function, θ, is estimated as 0.7 by regressing the log of profit on the log of capital using Greek firm-level data.

The profitability shocks, A_{it}, contain both an aggregate and an idiosyncratic component. The aggregate shocks are assumed to have a high and low value: $\{0.9, 1.1\}$. The serial correlation between the aggregate shocks is calculated as 0.8. We represent the aggregate shock process as a two-state Markov process with a symmetric transition matrix in which the probability of remaining in either of the two aggregate states is 0.8. The details of calculating the idiosyncratic shocks, a_{it}, are in section 4.1.3. We assume that the idiosyncratic profitability shocks follow an AR(1) process:

$$a_{it+1} = \rho a_{it} + \varepsilon_{it+1} \quad \text{where } \varepsilon_{it} \sim iid \;\; N(0, \sigma_{\varepsilon}^2) \tag{9}$$

We approximate this process by a discrete Markov process using the method outlined in Tauchen (1986). A time invariant Markov chain is defined by (Z, T), where $Z \in \mathbf{R}^n$ is a vector describing the states possible of the Markov process, and T is an

[21] r is set approximately at 3 percent which is the average real interest rate on government bonds in Greece

$n \times n$ dimensional transition matrix with elements (i, j) that express the probability of transition from state Z_i to state Z_j. Thus, the rows of T sum to unity.[22] The method proposed by Tauchen (1986) is used to create a discrete state space representation of the stochastic AR(1) process for the firm specific shocks. The idiosyncratic shocks take 11 different values. The serial correlation of the idiosyncratic shocks is 0.69. The standard deviation is 0.1. Table 7 presents the idiosyncratic shocks and the transition matrix of these shocks.

Table 7. Idiosyncratic shocks and their transition matrix

idiosyncratic shocks	**-0.1815**	**-0.1114**	**-0.0757**	**-0.0478**	**-0.0232**	**0**	**0.0233**	**0.0478**	**0.0757**	**0.1115**	**0.1815**	**sum**
-0.1815	0.4478	0.2159	0.1303	0.0824	0.0524	0.0328	0.0197	0.011	0.0054	0.002	0.0003	1
-0.1114	0.2159	0.2046	0.1652	0.1291	0.0983	0.0724	0.0509	0.0333	0.0194	0.0089	0.002	1
-0.0757	0.1303	0.1652	0.1571	0.1396	0.1188	0.0971	0.0757	0.0553	0.0363	0.0194	0.0054	1
-0.0478	0.0824	0.1291	0.1396	0.137	0.1273	0.1131	0.0957	0.0762	0.0553	0.0333	0.011	1
-0.0232	0.0524	0.0983	0.1188	0.1273	0.1278	0.1221	0.1113	0.0957	0.0757	0.0509	0.0197	1
0	0.0328	0.0724	0.0971	0.1131	0.1221	0.1251	0.1221	0.1131	0.0971	0.0724	0.0328	1
0.0233	0.0197	0.0509	0.0757	0.0957	0.1113	0.1221	0.1278	0.1273	0.1188	0.0983	0.0524	1
0.0478	0.011	0.0333	0.0553	0.0762	0.0957	0.1131	0.1273	0.137	0.1396	0.1291	0.0824	1
0.0757	0.0054	0.0194	0.0363	0.0553	0.0757	0.0971	0.1188	0.1396	0.1571	0.1652	0.1303	1
0.1115	0.002	0.0089	0.0194	0.0333	0.0509	0.0724	0.0983	0.1291	0.1652	0.2046	0.2159	1
0.1815	0.0003	0.002	0.0054	0.011	0.0197	0.0328	0.0524	0.0824	0.1303	0.2159	0.4478	1

The transition matrix for the idiosyncratic shocks is computed from the empirical transitions observed at the firm-level and reproduces statistics from the idiosyncratic profitability shock series.

4.2. Estimation Method: Indirect Inference

The vector of remaining structural parameters to be estimated is $\Theta \equiv (\gamma, F)$. The approach is to estimate these parameters by matching the implications of the structural model with key features of the data. The methodology that is used for this purpose is the structural empirical approach called indirect inference method. This method is explained by Gourieroux *et al.* (1993), Smith (1993), Gourieroux and Monfort (1996) and works as follows.

With an arbitrary set of parameter values and by using the Value Function Iteration method we solve the firm's dynamic programming problem.[23] After the model is solved for given Θ values, a 500 firms and 100 periods simulated panel data

[22] For some theory, see Ljungqvist and Sargent (2000, Chapter 1), Stokey and Lucas (1989, Chapters 8, 11 and 12) and Adda and Cooper (2003).
[23] See section 3.2.

are obtained using the created policy functions. This simulated data set is used to calculate the model analogues of the coefficients and/or moments we obtained using actual data. The reduced form equation we estimate using both the simulated and actual data is

$$\tilde{i}_{it} = \Psi_0 + \Psi_1 a_{it} + \Psi_2 (a_{it})^2 + u_{it}$$

where $\tilde{i}_{it}$ is the deviation of the investment rate of firm i in period t from the firm specific mean, a_{it} is the idiosyncratic profitability shock, $(a_{it})^2$ is the square term of a_{it}. The square term is included in order to take into account the non-convexities in the adjustment process. Denoting as Ψ^d the vector of moments from the actual data and as $\Psi^s(\Theta)$ the vector of moments from data simulated given Θ, the indirect inference routine looks for the structural parameter estimates that minimize the weighted distance between the two vector of moments.[24] More formally, the statistic we try to minimize with respect to Θ in order to find the structural parameter values is the following quadratic function:

$$J(\Theta) = (\Psi^d - \Psi^s(\Theta))' W (\Psi^d - \Psi^s(\Theta))$$

where W is a weighting matrix.[25] The vector of true moments is $\Psi^d = [\Psi_1, \Psi_2] =$ [0.322, 0.443]. Given the discontinuities in the model and the discretization of the state space, as it is the case in related studies, we use the method of simulated annealing in order to minimize $J(\Theta)$ with respect to Θ. As Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2006) notice, simulated annealing is the ideal algorithm for dealing with complex functions, first because it explores the function's entire surface and can escape from local optima by moving uphill and downhill and second, because the assumptions required with respect to functional forms are quite relaxed.

[24] As pointed by Gourieroux and Monfort (1996), minimizing the distance between the simulated data moments and the actual data moments will emerge consistent estimates of the structural parameters.
[25] We implement the 2x2 identity matrix.

4.3. Estimation Results

Using the indirect inference method, the structural parameters of the model proposed in section 3 are estimated. Table 8 gives the estimated values.

Table 8. Estimated Structural Parameters

Coefficients	Estimated values
γ	0.5164 (0.0130)
F	0.1557 (0.0035)

Note: standard errors are reported in parentheses

The structural parameters γ and F are significantly different from zero, indicating the importance of convex and fixed adjustment costs. It is essential to bring to reader's notice that the estimation results are affected by the fact that we are only exploiting the binary choice between zero investment and positive investment. In this sense, our results are not directly comparable with the results obtained by Cooper and Haltiwanger (2006), Bayraktar (2002), and Bayraktar, Sakellaris and Vermeulen (2006).

The estimated value of the coefficient determining the magnitude of the convex adjustment cost, γ, is 0.5164.[26] The estimated value of the coefficient determining the magnitude of the fixed adjustment cost, F, is 0.1557. This implies that a firm that undertakes an investment project faces a fixed adjustment cost of 15.57 percent of installed capital. The estimated value of the coefficient F is high compared to the estimates found by relevant studies. [27]

Now we focus on the comparison of the simulated data results with the actual data results. Table 9 shows the regression coefficients of the reduced form regression of investment rate on the profitability shocks using the actual data and the simulated data.[28]

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[26] Cooper and Haltiwanger (2006) estimate γ as 0.455, Bayraktar (2002) finds an estimated γ at 0.311 and Bayraktar, Sakellaris and Vermeulen (2005) estimate γ as 0.532.

[27] Cooper and Haltiwanger (2006), Bayraktar (2002), Bayraktar, Sakellaris and Vermeulen (2005) estimate F at 0.069, 0.029 and 0.031 respectively.

[28] The simulated data regression coefficients were obtained using the simulated data that were generated using the estimated values of Table 8.

Table 9. Actual Data versus Simulated Data: Regression Results

Coefficients	**Actual Data**	**Simulated Data**
a_{it}	0.322	0.322
$(a_{it})^2$	0.443	0.443

Note: The estimation technique is the least square. The dependent variable is the deviation of the investment rate from the firm specific mean.

Table 10. Moments of actual data versus moments of simulated data

Moments	**Actual Data**	**Simulated Data**
mean of investment rate	0.18	0.10
correlation ($\tilde{i}_{it}$, a_{it})	0.187	0.39
autocorrelation of inv. rate	0.17	-0.03
investment rate (> 0.2)	31.7%	13.8%
investment rate < 0	2.5%	16.9%

The estimated coefficients using the actual and simulated data are exactly the same. In Table 10 we also compare some moments of actual data and simulated data. The dynamics of the simulated data seems to be different than the dynamics of the actual data. The weakest result produced by the model compared to the actual results is the autocorrelation of the investment rate. While the actual value is 0.17, it is estimated as -0.03 by the model. One possible explanation for such a low estimated value might be related to the presence of financial frictions. The model is not working well in terms of the estimated autocorrelation of the investment rate due to the omission of financial market imperfections. Furthermore, it is possible that measurement error in the profit data is the cause of some of the difference in dynamics. Despite this, the overall investment rate is captured quite well by the model. The actual value of the average investment rate is 0.18 and it is estimated as 0.1 by the model. With regard to the contemporaneous correlation of the investment rate with the profitability shocks, while the correlation in the actual data is 0.19, we have a comparable estimation of 0.39. Now, with regard to the fraction of the observations corresponding to the different values of the investment rate, we think that the nonlinear effect of the profitability shocks is not perfectly captured as evidenced by a somewhat different fraction of firms having investment bursts. In parallel, the fraction of observations with a negative investment rate is estimated as 16.9 percent, while its actual value is 2.5 percent.

5. Why adjustment costs are important – Policy and modeling implications

Firm’s changes in input demands are liable to adjustment costs and economists are concerned of what those costs look like. This is for a wide range of reasons, many having to do with the ability to predict the effects of factor market policies at external shocks and furthermore, aggregate investment sums firms’ changes in their capital stock and measures responses that are determined by the structure and size of the adjustment costs. Therefore, GDP is partly determined by adjustment costs, as are labor productivity and total factor productivity. In addition, knowledge of structures of adjustment costs is crucial for predicting the possibly long and complex path of responses of capital demand to shocks, therefore should be a basic input into debates over the long run effects of policies that concern investment.

Specifically, to predict the effects of proposed policies or the possible impact of external shocks, we need to know (as Hamermesh and Pfann (1996) mention): 1) the source of the adjustment cost the firm is facing. Is it adjustment costs that generate slow adjustment, or does stickiness arise from other aspects of a firm’s behavior or market environment? 2) The structure of these costs. Without knowing the structure of the costs, the path of firm’s capital demand in response to shocks cannot be predicted, and 3) the size of adjustment costs. Higher costs associated with investment reduce the firms’ long-run demand for capital.

Elaborating these questions, we have found that slow adjustment is generated – and can be explained – by costs associated with changing capital demand. Adjustment costs are found to be statistically important, thus firms change their demand for capital more slowly than the shocks to capital demand warrant, due to the interference of these costs[29]. As far as the structure of the costs is concerned, the estimation results reported in Tables 8 and 10 indicate that a model which mixes both convex and non-

[29] Precisely speaking, we assume and verify that the reason for slow adjustment (once expectations about shocks are accounted for) is the costs associated with altering the demand for capital.

convex adjustment processes can match the moments calculated from firm-level data quite well. The conclusion that adjustment costs are not characterized by a symmetric quadratic structure (as is usually assumed) affects aggregate behavior.

Finally, with regard to the size of the adjustment costs, our findings indicate high costs associated with investment in the Greek (micro) economy. The estimated value of the coefficient determining the magnitude of the convex adjustment costs (γ) is found to be 0.5164, which is higher than the values structurally estimated by other authors for other countries.[30] Cooper and Ejarque (2001) estimate γ to be 0.149 in their study for USA. Cooper and Haltiwanger (2006), Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2005) estimate the value of γ to be very close to the value found here (namely, 0.5164) (see footnote 26 for details). The estimated value of the coefficient determining the magnitude of the fixed adjustment has been found to be high (higher than in most of the literature) (see footnote 27 for details). A Greek firm that undertakes an investment project faces a fixed adjustment cost of 15.57 percent of installed capital. The variation of our results compared to other studies most likely arises from differences in specification, as is discussed in section 4.3 (see p.22).

With respect to economic modeling, Wilcoxen (1993, p.96) in a previous article in this journal argues that it is important to understand the nature of adjustment costs because it determines the medium- and long-run supply elasticity: "…*since the elasticity is sensitive to even small departures of the adjustment cost parameter from unity, it is clearly inappropriate to assume adjustments costs are zero without considerable empirical evidence. This suggests that a fruitful area for future research is the empirical determination of adjustment cost parameters at the industry level. In addition, such research would help identify the underlying source of adjustment costs and would indicate whether these costs would be influenced by policy*". Goyal (1994), also in this journal, takes a step ahead and argues that it is important to know the structure of adjustment costs because it determines the long-run elasticity, which is

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[30] This parameter is investigated in many empirical studies. In general, the estimated value of this parameter is much higher in the literature (not structural estimation like this one). Hayashi (1982) estimates γ as 20. Gilchrist and Himmelberg (1995) find the value as 3. The thing is –as pointed out by Cooper and Haltiwanger (2006)- that these empirical results may not be accurate due to the presence of the measurement errors in Tobin's q. It is assumed that the marginal q is equal to the average q, hence it is possible that a measurement problem exists in calculating empirical q and this produces extremely high γ.

one of the most vexed questions in satisfactory modeling of dynamic Applied General Equilibrium Models.

Regarding policy issues, recent discussions stress that firm-specific aspects are not the unique determinants of capital adjustment. Government's fiscal activity is also important. Public policy plays an important role in the firm's capital investment decision and the cognizance of adjustment cost's source, structure and size has been shown to have a significant bearing on the effectiveness of fiscal policy. Turnovsky (1996), for example, picks up the argument that firm-specific aspects are not the unique determinants of capital adjustment and develops a one-sector endogenous growth model in which capital investment incurs adjustment costs that are related to governmental activity. He shows that the presence of adjustment costs causes a reduction in the equilibrium growth rate. In addition, he demonstrates that adjustment costs reduce the effects of capital taxes on the equilibrium growth rate and cause an expansion in productive government expenditure[31, 32].

Closing this section it should be noted that the results we obtain here will allow us to improve the predictions of the paths of aggregate investment based on the knowledge of the dispersion of underlying shocks. Furthermore, knowing that costs are not always symmetric and convex guides us to a better understanding of the likely impacts of changes in capital-market policies than we obtain if we rely on the standard assumption. Last, but not least, this paper gives incipient clues and hints of how (stochastic) aggregation maps microeconomic behavior into macroeconomic relations.

6. Conclusions

In this paper a dynamic model of investment for Greek manufacturing firms is estimated. A balanced panel dataset of 1419 firms on 9933 observations for the period 1996-2002 has pointed strong evidence of inaction and lumpy investment. On account of these empirical observations, and since descriptive statistics should be taken as a "guide", we have adopted a model that takes into consideration total irreversibility of

[31] See also Ott and Soretz (2006) who extend the work of Turnovsky (1996) by assuming that adjustment costs are a function of governmental activity.

[32] The introduction of the governmental activity into the adjustment cost function can be an interesting extension.

investment and includes not only convex but also non convex adjustment costs. The adjustment cost function we assumed included both quadratic and fixed components.

We have estimated the structural parameters of the model using the indirect inference method. The indirect inference procedure works as follows. First, we solve the firm's dynamic programming problem for arbitrary values of the structural parameters and generate the corresponding optimal policy functions. Second, we use these policy functions and arbitrary initial conditions to generate simulated data. Third, this simulated data set is used to calculate the analogues coefficients obtained from the regression of the actual data. Finally, using the simulated annealing algorithm we estimate the structural parameters.

The results indicated that the structural model suits the data adequately. The structural parameters γ and F are significantly different from zero, indicating the importance of both convex and fixed adjustment costs. This rejects the neoclassical model with convex adjustment costs only and buttresses up the argument that adjustment costs are more complex than we once thought. Our estimates imply that frictions are important in determining firm's investment dynamics: traditional representative agent models with convex costs of adjustment only seem to be incapable of capturing the dynamics of investment and capital accumulation.

One of the gains to structural estimation presented in the present paper is to use the estimated parameters for policy analysis. Our next work will be the evaluation of the estimated model in terms of its predictions of the (dis)aggregate effects of an investment tax credit.

An issue that we plan to explore further is whether the presence of non-convexities at microeconomic level matters for aggregate investment. Whether, for example, the aggregation of individual agents facing non convex (lumpy) adjustment costs generates differences in the paths of aggregate investment to external shocks and whether linearity in the underlying adjustment cost structure determines the paths of business cycles. This issue of aggregate implications has already drawn considerable attention in the literature. Caballero, Engel and Haltiwanger (1995) find that introducing the nonlinearities created by non-convex adjustment processes can improve the fit of aggregate investment models for sample periods with large shocks. Cooper, Haltiwanger and Power (1999) find that there are years where the interaction of an upward sloping hazard and the cross sectional distribution of capital vintages matters in accounting for aggregate investment.

Whereas the analysis has taken labour as flexible factor of production and already being maximized out of the problem, the adjustment cost function could be augmented to include interactions between labour and capital inputs. In future, our study will gravitate to this interesting topic too.

Data Appendix

Sample Selection

The source of the data set used in this paper is the ICAP databank, which is a database providing financial, statistical and market information for the publicly traded companies in Greece. The data set covers, not only the big manufacturing firms, but almost all the Greek manufacturing sector. For our analysis we pooled all the active Greek manufacturing firms that ICAP database had available information for the period 1996-2002. The elimination of firms is conducted following a number of steps:

1. We filter the data depending on the availability of the plant, property and equipment data points. We delete firms with missing data points for the book value of capital stock on plant, property and equipment. The total number of firms after this elimination is 2097. These firms comprise a balanced panel of 14679 observations over the period 1996-2002.
2. We only keep firms if they have profits information. This leads to 1690 firms on 11830 observations.
3. We do not accept this as our final dataset. We need to delete the firms which have involved in significant acquisitions or mergers. There are different ways to eliminate these firms. Bayraktar (2002) adopts the method that Gilchrist and Himmelberg (1995) propose and excludes the firms whenever

$$\left| G_t - G_{t-1} - I_t + R_t \right| > 0.15 G_{t-1}$$

where G_t is the book value of the capital stock, I_t is nominal capital expenditure and R_t is the retirement of capital. We do not use this formula. Following Bayraktar, Sakellaris and Vermeulen (2005), practically we assume that investment rates higher than 90 percent are measuring a merger or acquisition. We exclude from our panel all the firms that display investment rate over 90 percent in any year among the period 1996-2002. This leads to our final balanced panel dataset of 1419 firms on 9933 observations for the period 1996-2002. Every firm has exactly 7 observations (6 observations for investment).

Description of the Variables

Raw variables from the ICAP CD-rom:

LAND AND ESTATES

BUILDINGS AND STRUCTURES

MACHINERY AND EQUIPMENT

NET PROFITS: the nominal book value of net profits (net of cost of production).

Constructed variables

Book value capital stock, $p_t K_t$ *:* the book value of the capital stock was constructed by the calculation *LAND AND ESTATES* + *BUILDINGS AND STRUCTURES* + *MACHINERY AND EQUIPMENT* + *INTANGIBLE FIXED ASSETS*

Investment at current prices, $p_t I_t$ *:* since gross investment is not directly available from ICAP database, it has to be constructed using depreciation and capital stock observations. We use the accounting identity $p_t I_t = p_{t+1} K_{t+1} - p_t K_t (1-\delta)$.

Investment price deflator: was taken from OECD data source ("deflator for total investment"), (based year 1995)

Real investment, I_t *:* is constructed as investment at current prices deflated by the investment price deflator.

Real capital stock, K_t *:* constructed as book value capital stock deflated by the investment price deflator.

Investment rate, $\left(\frac{I}{K}\right)_t$.

Greek GDP deflator: was taken from OECD data source (based year 1995)

Real net profits: constructed as net profits deflated by the Greek GDP deflator.

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Investments in R&D and business performance. Evidence from the Greek market.

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ABSTRACT

The purpose of the present paper is to discuss the question: are investments in R&D, innovation and new technologies, intangible factors of business performance? There is a great controversy concerning the relationship between profitability and investments in research and development. Many studies have failed to identify consistent positive returns from R&D and IT investments, and the paradox has been termed as the "IT productivity paradox". Most of the optimistic researchers argue that the disappointing results are due to mismeasurement errors, problematic design of the research and time lags between learning and adjustment, because R&D investments can take several years to show results. In our research, we apply a panel data analysis using data from industrial and computer companies listed in the Athens Stock Exchange, for the period 1995-2000. We find that although the R&D investments have a negative influence on profitability for the year of the investment, they can show strong positive relation after two years.

Keywords: Performance, R&D, profitability, firm level data, Greek market, productivity paradox, R&D strategy.

JEL Classification: O300, L250, M200, L190

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1. Introduction

In a competitive environment, firms are forced to adopt strategies in order to confront competition, increase profitability and market share. R&D investment has an essential role in these strategies, although it has distinguished characteristics from other investments. Since more than half of the investments are associated with salaries of skilled – expert workers and scientists, the degree of uncertainty associated with its output may influence the investment rate over time (Hall, 2000). R&D investment generates profits with a time lag (Aboody and Lev, 2001; Jefferson, 2006), and hence should be sustained at a certain level (Hall 2002).

The continuous substitution of knowledge (intangible capital) for physical (tangible capital) the last decades, has shown the important role of R&D on the performance of the firms (Lev, 1999). R&D investment has been studied from several different perspectives. Thorough research using a production function approach has been done by Griliches as early as 1979. Verspagen and Los (2000) researched the R&D spillovers and productivity, while Hall (2002) studied the financing of R&D. Aboody and Lev (2001), Ding, Stolowy and Tenenhaus (2007), Jefferson , huamao, Xiaojing and Xiaoyun (2006), studied the time lag of R&D on profitability and the contribution to the future earnings of the firm. In addition to those studies, Lev and Sougiannis (1996) found a positive correlation between R&D expenditures and economic growth.

The questions addressed in this paper aim to research the influence of R&D on profitability, the time period for profit realization and the existence of decreasing returns.

We used data from the balance sheets of 36 industrial and computer firms listed in the Athens Stock that report R&D stock, from the total 143, for the period 1995-2000.Using panel data estimations, we found that R&D needs at least two years to positively affect profitability. Moreover, this impact exhibits decreasing returns.

The paper is organized as follows: Section 2 gives the theoretical framework. Section 3 describes the data, presents the methodology and discusses the empirical results. Finally, section 4 offers some concluding remarks and policy implications.

2. Theoretical framework

R&D and implementation of new technologies, for products development and innovative production processes, are used in order to provide differentiation that can yield competitive advantage and lead time over rivals (Mansfield, 1968; Baily, 1972). Hence, the firm invests in R&D and innovation to achieve market share and monopolistic profit.

Hall (2000) states, that more than 50% of the R&D spending is associated with salaries and wages of highly educated scientists and engineers. Their efforts create an intangible asset (know how), from which profits in future years will be generated. Low investment in R&D reduces innovation and knowledge creation, which in turn reduces productivity as well as investments in both physical and human capital (Rogers, 2005).

R&D has generally been ignored, partly due to data availability problems. Sougiannis (1994) notes that most of the results that show no significant relationship between R&D and future benefits, may be due to sample sizes, research design, statistical techniques and quality of the R&D data used. Studies in research intensive industries show that R&D investments give above average returns (Grabowski, 1978).

A business unit with higher productivity is generally more profitable. There are many other factors that influence performance, that we should take into consideration in order to check the importance of innovative intangible capital stock.

Hence, we posit the following hypothesis.

Hypothesis 1. R&D stock is related to profitability.

The time lags are a major concern in the data and analysis. First of all a research may take a few years to complete. After completion, it may take a couple of years to start showing results (Griliches, 1979). This may be one of the most important reasons to check variation over time and to research more than 5 years of firm level data. Some of the studies use 15 years of data.

Jefferson (2006) finds that the returns to industrial R&D appear to be at least three to four times the returns to fixed production assets. There is a direct positive correlation between R&D expenditures and economic growth. Lev & Sougiannis (1996) found that the useful life of R&D varies from 5 to 9 years, while Aboody & Lev (2001) conclude that the estimated duration of the benefits from R&D projects is seven years and most of the operating income benefits are generated in 3 years from the R&D investment. Hence, we posit the following hypothesis.

Hypothesis 2. There is a time lag for the R&D stock to show results.

If we assume the production function exhibits the usual properties, then the R&D stock as a production factor should exhibit decreasing marginal returns. Thus, we posit the 3rd hypothesis.

Hypothesis 3. The R&D stock exhibits decreasing returns.

3. Data, Methodology and Empirical Results

We used data from the balance sheets of 36 industrial and computer firms listed in the Athens Stock that report R&D stock, from the total 143, for the period 1995-2000. The firms are the most important manufacturing and computer firms in Greece.

We define gross profit to sales ratio (*GPSL*) as a proxy for business performance. We used the gross profit to sales ratio as the depended variable in our model, because it is more closely related to monopolistic profit.

Firms that report R&D investments in their balance sheets, include research and development expenditures for new products development, innovations in production, software systems, brand development and other intangibles. Hall and Hayashi (1989), state that R&D is an important intangible capital that can lead to more long-lasting and supranormal returns; it is embodied in the firm and its employees and includes knowledge, accumulated know-how, technical expertise, trade secrets, patents, etc. Knowing that, we used the R&D stock to total assets, denoted as *RDTA*, as an explanatory variable in our model.

We finally used the following control variables: first, the cost of goods sold to inventories ratio denoted as *CGSINV*, as a proxy for the corporate management and second the size of the firm proxied either by the logarithms of sales (*SIZE*) or by the logarithm of fixed assets (*LFA*).

Tables 1 and 2 present the descriptive statistics and the correlation matrix of the variables used in our models. Data show a 28,4% average gross profit to sales ratio and an average of 1,8% R&D stock to total assets. In accordance to our findings, Voulgaris, Asteriou and Agiomirgianakis (2004), also calculated an average of 25% for gross profit ratio for SMEs and an average of 28% for LSEs, in their sample from the manufacturing sector.

Following the discussion of the previous section, the relationship between firms' performance and the explanatory variables is modeled as follows:

Profitability = f(research and development, control variables)

Where *GPSL* stands for profitability, *RDTA* with one and two lags stands for research and development and *SIZE*, *LFA* and *CGSINV* as control variables. Finally, to test the 3rd hypothesis for decreasing returns to R&D we included the squared *RDTA* with two lags.

Table 3 presents the panel estimations. In estimating panel data the unobserved effect or individual heterogeneity is random and should be tested for random effect or fixed effect. If the unobserved effect is uncorrelated to the observed explanatory variables ($cov(x_{it}, c_i)=0$, $t=1,2,\ldots T$) is called random effect otherwise fixed effect. Hausman test suggested, in our case, that the unobserved effect is correlated to the observed explanatory variables and therefore the fixed effect method is more robust than random effects analysis for the estimation of the parameters. The cost of this robustness is the exclusion of the time-constant observables. However, since our data set does not include any time constant observable explanatory variable, this cost is relatively low.

We conclude that R&D investments have a negative influence on performance, for the year following the year of the investment, since the novelty of the methods introduced to production processes requires a learning and adjustment period. The strong positive coefficient on the $[RDTA]_{t-2}$ term explains that there is a positive influence of R&D on the profitability of the firm on the following 2 years. This means that, we have to wait for 2 years after the investment in order to have strong positive returns in *GPSL*. Hence, our first and second hypotheses are valid and R&D is related to profitability and there is a time lag in order for the R&D investments to show results.

Based on our findings, we suggest smooth and consistent investments in R&D. The managers have to wait for 2 years in order to have positive results from R&D. From our experience from the internet industry, internet companies need a period of two years from new product development and R&D investments, in order to increase sales and profits. Hence, companies with late reaction to the competition need around 2 years to react to the new technologies, and another 2 years after implementation, concluding to a time span of four years. Branch (1974) finds that there is a lag of 4 years between introducing an innovation to practice and receiving a patent on it. That is why he used the patents received in year t as an index of a firm's R&D output in year t-4.

The negative coefficient on the $[RDTA]_{t-2}^{2}$ term suggests that the third hypothesis for the existence of decreasing marginal returns is supported by the data. Therefore, the continuous increase of R&D share to total assets is not followed by equivalent increase in profitability and even more the level of R&D investment has an upper limit after which profitability decreases. In order to estimate the upper level of *RDTA*, we take the partial derivative of GPSL with respect to $[RDTA]_{t-2}$ from the (A2) model in Table 3. Hence:

$$\frac{\partial GPSL}{\partial [RDTA]_{t-2}} = 0 \Rightarrow b_1 + 2b_2[RDTA]_{t-2} = 0 \Rightarrow [RDTA]_{t-2} = 0{,}157$$

Where b_1 is the estimated coefficient of the $[RDTA]_{t-2}$ and b_2 is the estimated coefficient of the squared $[RDTA]_{t-2}$. Thus, the upper limit for R&D as share of total assets is 15.7% and after that profitability decreases. Using the partial derivative of *GPSL* with respect to $[RDTA]_{t-2}$ from the (A2) model, we also find that an increase on the share of R&D to total assets by of 1% leads to an increase on *GPSL* by 1.69%, in the following two years.

$$\frac{\partial GPSL}{\partial [RDTA]_{t-2}} = b_1 + 2b_2[RDTA]_{t-2} = 1.975 - 2 \cdot 6{,}269 \cdot 0.023 = 1{,}69$$

CGSINV show a negative influence on performance in all our models. This means that lowering the stock the performance decreases, in contrast older findings that, it is large inventories that create a drag on firm's performance (Chhibber and Majumdar, 1999). This may be due to the fact that further lowering inventories leads to operational and sales problems.

Finally, the size has a negative influence on gross profit margin (in contrast to the theory). This may be true for Greece as the major companies are old, former state owned companies, and we find in literature that the age of the firm has a negative influence on performance (Majumdar, 1997). Moreover, although a positive relationship between size and profitability is expected, firms that grow at a rate faster than that which the entrepreneur can manage may experience diseconomies of scale which reduce profitability (Glancey, 1998).

4. Conclusions and policy implications

In our study we undertook an empirical investigation using panel data methodology for 36 industrial and computer companies listed in the Athens Stock that report R&D stock, for the period 1995-2000. Our findings suggest that the effect of R&D investment on profitability becomes positive after a period of two years with decreasing returns.

More specifically, the production costs tend to increase in the short run, because new product development, new production methods and information technology, need time to show results, since the novelty of the methods introduced into the production processes creates turmoil during the adjustment period. That explains the negative relation of R&D to profitability for the subsequent of the investment year. Finally, 2 years after the R&D investment, the new methods and improvements are fully functional and absorbed and we can see positive returns on profitability, but with decreasing results.

Although we have results in accordance to the theory, further research should be done using data from the income statements of the firms, as many of the R&D expenditures are calculated in the income statements and not to the balance sheet. Only the 30% of the companies in the Athens Stock Exchange calculate R&D expenditures in their balance sheet. Matteucci and Sterlacchini (2005), also found that only 34% of their sample from Italian manufacturing firms, do report R&D expenditures. We can also find in the literature that most companies do not capitalize R&D, even when accounting standards allow them the option. The difficulty on modeling such a research is that many of the R&D expenditures are calculated in the income statements as production costs and not specifically as an R&D figure. Furthermore, R&D and innovation is a value that many times is not calculated in the financial statements. Lev (2003), comments that most companies do not report how much they spend on employee training, on brand enhancement, or on software technology. Most of the times, R&D and innovation is an intangible asset that has to do with entrepreneurship and the owner's innovative ideas. Many of the assets bought for production, involve high technology and R&D, but the extra value is paid as a product and is not calculated in the balance sheet. The companies should calculate this extra value and take it into account in the intangibles, with annual depreciation, and not just calculate it as expenses in the income statement. Though, this direction deals with the personality and education of the entrepreneur. Lev (2003) comments that managers tend to manipulate and immediately expense R&D expenditures in order to meet profit goals. The same problem arises when many innovative products and R&D expenses are paid through operating leasing and hence they are also calculated as production expenses in the income statement.

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Appendix

Table 1: Descriptive Statistics

	Mean	Std Dev	Minimum	Maximum
GPSL	0.284	0.117	0.058	0.597
RDTA	0.018	0.030	0.000	0.187
$[RDTA]_{t-1}$	0.022	0.036	0.000	0.201
$[RDTA]_{t-2}$	0.023	0.037	0.000	0.201
SIZE	17.612	1.182	15.669	21.909
LFA	17.052	1.396	13.143	20.732
CGSINV	7.051	11.674	0.869	70.446

Table 2: Correlation Matrix

	GPSL	$[RDTA]_{t-1}$	$[RDTA]_{t-2}$	$[RDTA]^2_{t-2}$	SIZE	LFA	CGSINV
GPSL	1						
$[RDTA]_{t-1}$	-0.629	1					
$[RDTA]_{t-2}$	-0.752	0.934	1				
$[RDTA]^2_{t-2}$	-0.120	0.853	0.921	1			
SIZE	-0.273	-0.103	-0.050	-0.073	1		
LFA	-0.150	-0.292	-0.260	-0.327	0.783	1	
CGSINV	-0.165	0.108	0.121	0.033	0.095	-0.020	1

Table 3: Panel estimations: Dependent variable GPSL

	Model A1	Model A2	Model B1	Model B2
$[RDTA]_{t-1}$	-0.823**		-0.698**	
	(-2.558)		(-2.317)	
$[RDTA]_{t-2}$	1.041***	1.975***	0.950**	1.961***
	(2.826)	(2.906)	(2.566)	(2.886)
$[RDTA]^2_{t-2}$		-6.269*		-6.412**
		(-1.948)		(-01.996)
CGSINV	-0.102*	-0.106*	-0.129**	-0.125**
	(-1.688)	(-1.720)	(-2.097)	(-2.022)
SIZE	-0.035***	-0.018*		
	(-2.649)	(-1.665)		
LFA			-0.015**	-0.960*
			(-2.603)	(-1.720)
R^2 adjusted	0.929	0.926	0.929	0.926
F-statistic	36.142	33.498	37.514	34.588
Prob(F-statistic)	0.000	0.000	0.000	0.000
Hausman test	$x^2(4) = 1.224$	$x^2(4) = 5.507$	$x^2(4) = 2.478$	$x^2(4) = 7.609$
	p=0.874	p=0.239	p=0.648	p=0.107

T statistic in parentheses.
***, **, * indicate a significance at the 1%, 5% and 10% levels respectively.