Technical change, efficiency change and institutions: Empirical evidence for a sample of OECD countries

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I. Introduction

In recent decades, the explanation of the economic dynamics of nations has rested on endogenous growth literature, which emerged in the early 1990s due to the incapacity of the neoclassical model to explain growth rate divergence at international level. From among the diverse currents of this theory, the present study centres on the Schumpeterian proposal defended by Aghion and Howitt (1992, 1998). In this context, this paper aims at studying the determinants of total factor productivity (TFP) growth in developed countries, with special emphasis on institutions.

An initial and important contribution of the Schumpeterian framework is the explanation of the differences observed in the growth rates of the TFP of nations, on the basis of an endogenously determined innovation rate. Innovation may either improve previously existing technology, so that the technological frontier shifts (technical change), or alternatively promote approximation to the frontier, by facilitating the implementation of technology developed elsewhere (efficiency change).

To evaluate the dissimilar influence of these two aspects of innovation, the present study calculates a Malmquist productivity index for 15 OECD countries in the period 1989-2004 and decomposes it into two components (technical change and efficiency change), in line with the numerous contributions building on the pioneering works of Färe et al. (1994) and Bjurek (1996).

Having distinguished the two components of TFP growth, two equations are estimated to determine the explanatory factors of each component, following the suggestions of Coe et al. (2009) and adapting the proposal of Howitt (2000). In the case of efficiency change, an analysis is also made of the significant role that Schumpeterian proposals reserve for the distance to the technological frontier: in principle, positive international technological spillovers give an advantage to latecomers, see Gerschenkron (1962). However, taking advantage of these spillovers requires that nations can exploit the knowledge of the leaders, which Howitt and Mayer-Foulkes (2005) call implementation capacity.

Finally, the Schumpeterian model admits the influence of policies and institutions in the evolutionary dynamics of both technical change and efficiency change. Institutions and policies will have, together with the technological effort, a clear influence on economic growth. However, as Aghion and Howitt (2006) state, they will do so differently depending on the distance of the country to the technological frontier. As a result, this study incorporates institutional variables, in line with the most recent literature (Coe et al. 2009, Bouis et al., 2011, Afonso and St. Aubyn, 2010, Kim and Lee, 2009) which emphasizes the influence on the evolution of TFP of institutional and political variables such as public regulation, trade policies, restrictions on foreign direct investment or copyrights.

The nature of many of the variables in this model recommends using the advanced instrumental approximations and econometric panel techniques to control for endogeneity. Consequently, an augmented version of the Arellano and Bover (1995) estimator for dynamic panels is applied to the sample.

The article comprises seven sections, including the introduction. The second focuses on the methodological issues and the theoretical models which explain technical change and efficiency change. The third describes the sample and the data employed. The fourth presents a descriptive analysis of the dependent and institutional variables. In the fifth section an estimation of the models and the main results are exposed. These are compared with the results of previous studies in the sixth section. Finally, the seventh section summarises the most important conclusions of the research. The paper is accompanied by an annex which shows the statistical relationship existing among the variables of the models.

II. Methodological issues

II.1. Total factor productivity: measurement and decomposition

Traditionally, the change in TFP can be evaluated through distinct indices, such as those of Törnqvist and of Malmquist. Conceptually, there exist important methodological differences between them. The Törnqvist approximation relies on cost shares or other value-based weights, which implies a need for price indices as well as quantity indices, whereas the Malmquist productivity index (hereafter MPI) only requires quantity indices (Nera Economic Consulting, 2006). In addition, the Törnqvist index assumes that prices are competitive and that factors are remunerated by their marginal product; in other words, that factor income shares are suitable weights to aggregate factorial productivities in TFP. Conversely, the MPI is constructed from production functions and the share quotas are the result of the shadow prices of the linear programme which allows the estimations to be obtained. A third feature of the MPI lies in its ability to separate "technological change" and "catch-up", whereas the Törnqvist index does not provide this kind of valuable information. Finally, the Törnqvist index is a non-frontier approach and considers that all the evaluated units (countries) are technically efficient. In distinction, the MPI is a frontier approach which measures the efficiency of evaluated units while assuming the possibility of inefficiency. Because of the inherent advantages of this last index, in this paper the TFP will be proxied by the MPI.

In recent decades numerous studies have measured both TFP and its two components by means of the calculation and decomposition of the MPI. Notable among those who have measured it from a parametric approach are Nishimizu and Page (1982) and Fecher and Perelman (1990, 1992). From among those using non-parametric methods like DEA (data envelopment analysis) to estimate the MPI, mention should be made of Färe et al. (1994) and Perelman (1995). More recently, good examples are Maudos et al. (2000), Angeriz et al. (2006), Färe et al. (2008), Delgado-Rodríguez and Álvarez-Ayuso (2008), Ezcurra et al. (2009) and Álvarez-Ayuso et al. (2009, 2011), using data from European economies; Margaritis et al. (2007) and López-Pueyo et al. (2008) use information from OECD countries, while Saranga and Banker (2010) perform their study using a database of companies in the Indian pharmaceutical industry. In this paper the non-parametric DEA approach will be used.

The calculation of the MPI may be performed in different ways; depending on the set of time data taken into consideration in the construction of the reference frontier (see Tulkens and Vanden Eeckaut, 1995). The first alternative is to construct, in each time period *t*, a production space which only considers observations within that period. The reference frontier is composed in this case by the best practices reached within such period and, therefore, is termed the *contemporaneous* frontier. The second alternative consists of constructing a referential production space in each time period *t* which takes into consideration the observations of previous periods. Thus, the production frontiers of subsequent periods are nested and sequentially constructed, and they are known as *sequential* frontiers[1]. In the present paper a sequential approach is adopted, since, although at sector level its employment is controversial (Pastor and Lovell, 2005) for the economy as a whole it is unwise to assume the possibility of technical regress.

Additionally, the calculation of the MPI by means of DEA requires the choice of the assumption relative to constant returns to scale (CRS) or variable returns to scale (VRS). In this paper, the estimation of the MPI and its decomposition are carried out in a framework of CRS. Two reasons support this decision. The main argument is rooted in the well documented link between the MPI and the average product notion of TFP (ratio of output to inputs). As several papers have shown,[2] the MPI measures TFP if, and only if, the distance functions involved in its calculation are evaluated relative to a CRS technology (Grosskopf, 2003). A second argument in favour of the CRS technology is related to the aggregated country level data involved in our study where, as Coelli and Prasada Rao (2005) explain, the only sensible option is to use a CRS technology. An illustration of the suitability of the CRS assumption when working with aggregate country level data, is that all the papers involved in the measurement of the TFP growth of countries using the MPI have implemented the CRS framework (see Färe et al, 1994, Maudos et. al, 2000, Salinas-Jiménez, 2003, Färe et al.,2006, Margaritis, et al. 2007, López Pueyo and Mancebón, 2010, Ceccobelli et al., 2012).

A final important issue to solve when the DEA is applied to measure and decompose the MPI is related to the orientation of the model of mathematical programming that allows to obtain the values of the MPI and its two components. Two are the options: input-oriented models or output oriented models[3]. At macroeconomic level, the output orientation approach is the more plausible assumption, since achieving a maximised social product with a given resource endowment (instead of realizing a given social product objective with a minimized amount of inputs) is closer to the objectives of growth policy (Krüger et al., 2000).

The Malmquist index with a sequential and output-oriented approach may be written as:

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[1] The contemporaneous frontier method involves assuming that technical regress is possible. In fact, constructing contemporaneous frontiers enables best possible practices found in year *t+1* to be below those attainable in year *t*, since there is no relation in the construction of the two referential technologies. This situation does not occur in the case of sequential frontiers, where it is assumed that all preceding technologies are feasible in each period. In other words, in the sequential approach it is assumed that once techniques have been acquired they are available to be adopted forever (Fried et al. 2008), since the frontier is erected using the best practices prior to the evaluation period. For a more detailed explanation of the differences between the sequential and the contemporaneous approaches see Shestalova (2003).

[2] See Färe et al.(1998) and Berg et al. (1992) for the single input, single output case; Grifell-Tatjé and Lovell (1995) for an empirical demonstration and Førsund (1997) for the general case.

[3] For more details about how data envelopment analysis models work, see Cooper et al. (2000).

$$M^{S}{}_{O}(x^{t},y^{t},x^{t+1},y^{t+1})=\left[\frac{D^{St}_{o}(x^{t+1},y^{t+1})}{D^{St}_{o}(x^{t},y^{t})}\,\frac{D^{St+1}_{o}(x^{t+1},y^{t+1})}{D^{St+1}_{o}(x^{t},y^{t})}\right]^{1/2} \qquad [1]$$

where x^t *and* y^t denote, respectively, the inputs and outputs used by a country in the period *t*. $D^t{}_O$ stands for the output oriented distance function for each country (see Shephard, 1970). The superscript ^{S} indicates that the reference for comparisons is a frontier constructed sequentially. In our empirical work, the output oriented distance functions will be calculated by solving a DEA mathematical programming model.

This Malmquist index can be disaggregated, using simple mathematical operations, into two elements, which proxy the efficiency change (EC) and the technical change (EC) of the country under evaluation (see Färe et al., 1994):

$$M^{S}{}_{O}(x^{t},y^{t},x^{t+1},y^{t+1})=\frac{D^{St+1}_{o}(x^{t+1},y^{t+1})}{D^{St}_{o}(x^{t},y^{t})}\left[\frac{D^{St}_{o}(x^{t+1},y^{t+1})}{D^{St+1}_{o}(x^{t+1},y^{t+1})}\,\frac{D^{St}_{o}(x^{t},y^{t})}{D^{St+1}_{o}(x^{t},y^{t})}\right]^{1/2} \qquad [2]$$

The first quotient measures the degree of convergence with the production frontier met by the evaluated country between period *t* and *t+1* (what is known as efficiency change; hereafter, EC). Values over 1 for this indicator denote an approximation to the frontier or convergence. Values below 1 correspond to efficiency losses.

The second component, the product between square brackets, approximates technical change (hereafter TC) or the technological innovation effect resulting from the shifting of the production frontier between periods *t* and *t+1*. This component, in contrast to that obtained from its contemporary equivalent, only registers the changes due to expansions in the set of production possibilities, since it does not admit contractions of the frontier. Values over 1 in this case signify technical progress.

By decomposing the MPI, the two dependent variables in the present study are obtained: change in technical efficiency (diffusion) and technical change (innovation). In the section that follows we explain the empirical model in order to disentangle the determinants of those variables.

II.2. Total factor productivity: Specification of the models

In accordance with Grosskopf (1993), in a world in which inefficiency exists, productivity growth is defined as the net effect of shifts in the production frontier (TC) and of variations in efficiency (EC). Technical change emerges from alterations in the practices of those who use leading-edge technologies and change in efficiency emerges from other types of improvements, such as learning by doing, the diffusion of technological knowledge or good business management. The distinction is important from the political point of view: if productivity grows slowly due to problems of efficiency, policies aimed at reducing inefficiency may be more effective should they aim at stimulating productivity improvement rather than innovation development.

Following Howitt (2000), TFP change can be explained by innovation and catching up. Empirical applications have used a single equation to estimate the role of each of these variables to explain TFP change, as equation [3] shows:

$$\Delta\ ln\ TFP_{it} = \alpha_{TFP0i} + \beta_1\ (X/Q)_{i,t-1} + \beta_2\ (X/Q)_{i,t-1} * ln\ (A^{max}/\ A_i) + \gamma_1\ F_{it} + \varepsilon_{TFPit} \qquad [3]$$

where $\Delta\ ln\ TFP_{it}$ is total factor productivity change registered in country i in the period t; (X/Q) is a variable measuring the research intensity of country i; A^{max}/A_i is the distance to the technological frontier; F are the control variables; β_1, β_2, *and* γ_1 are the parameters to obtain the impact of technological capital and the impact of the control variables on TFP change; lastly, ε_{TFP} is the error term. A key feature of our paper is to include institutions as a control variable to measure their effects on the determinants of TFP.

The explanation of the two components of TFP change adapts Howitt's work (2000), employing two equations:

$$\Delta\ ln\ TC_{it} = \alpha_{T0i} + \beta_3\ (X/Q)_{i,t-1} + \gamma_2\ F_{it} + \varepsilon_{TCit} \qquad [4]$$

$$\Delta\ ln\ EC_{it} = \alpha_{E0i} + \beta_4\ (X/Q)_{i,t-1} * ln\ (A^{max}/\ A_i) + \gamma_3\ F_{it} + \varepsilon_{ECit} \qquad [5]$$

where $\Delta\ ln\ TC$ is the technical change registered for country i in the period t; $\Delta\ ln\ EC$ is the efficiency change registered in country i in the period t; β_3 *and* γ_2 are the parameters to obtain the impact of technological capital and the impact of the control variables on technical change; β_4 *and* γ_3 are the parameters to obtain the impact of technological capital and that of the control variables on efficiency change; and ε_{TCit} and ε_{ECit} are error terms.

To explain TC, the quotient between X and Q is used to proxy technological intensity, calculated by the ratio between a variable X, representative of innovation or implementation, and a variable Q, representative of product proliferation. It was decided to proxy X by stocks of R&D or of patents, as these are more representative measures of technological intensity than flow variables (Islam, 2009). Q is proxied by Gross Domestic Product (GDP). In accordance with Schumpeterian theories, *R&D-based innovation* has a positive and statistically significant impact on technical change, since it affects the capacity of a country to create knowledge or innovation. Thus the higher the X/Q, the higher technical change will be.

The technological intensity variable also appears in the explanation of EC. In effect, efficiency change is a function of the so-called absorptive capacity or implementation capacity. This in turn is determined by the technological effort made by a specific country weighted by the distance to the frontier. This interaction will allow for the evaluation of the final effect of two counterbalanced forces. As Howitt (2005: 11) states: "Although Gerschenkron's (1962) 'advantage of backwardness' is a strong force towards convergence of growth rates, the observed divergence between the rich and poor countries suggest that there may be countervailing forces at work on the evolution of the gap".

Due to the differences existing in institutions, climate or qualifications for example, the technology developed in one country cannot be used in another without modifications. These factors may produce the latecomer disadvantage and consequently follower countries must invest in R&D to obtain a true advantage from technological transfer. In accordance with the models of Howitt (2000, 2005), when research intensity interacts with the distance to the frontier, this variable, considered in the explanatory model of EC, must exert a positive and statistically significant effect[4].

With regard to control variables (*F*), it is assumed that they may influence the capacity of an economy to shift the technological frontier or to approach it, whether temporarily or permanently. Among these variables the *Schumpeterian paradigm* points to institutions and policies as the most important. So, in this paper some indicators of anti-competitive policies are included in equations [4] and [5] (see sections III and IV.2).

As reflected in Aghion et al. (2006)[5], the relation between competition, innovation and efficiency can produce diverse results. On the one hand, more intense competition encourages companies to innovate, with the aim of escaping from the competition (*escape effect*). On the other, in the less competitive markets, rents are greater, and thus the potential profits from innovation are also higher[6].

This latter posture is defended by the pioneering models of endogenous growth (Aghion and Howitt, 1992, among others) and the literature on industrial organisation (which considers that competition in the product market produces lower innovation activity). This is because the monopoly rent obtained by successful innovators is reduced (*Schumpeterian effect*). This conclusion is obtained under the assumption that innovation is performed by outsiders, so pre-innovation income is nil and, consequently, the profit from the innovation is identical to subsequent income.

More recent models of endogenous growth (Aghion and Howitt, 1998, among others) consider that the incentive to innovation depends on post-innovation rents and on the difference between post and pre-innovation rents. In this case, the greater competition in the product market, insofar as it reduces pre-innovation rents more than post-innovation rents, may generate greater innovation and growth. In summary, competition can raise the incremental profit of innovating, encouraging investment in R&D via the *escape effect*.

Following Aghion et al. (2005), competition will affect innovation depending on the characteristics of the sector. In so-called *neck-and-neck* industries, in which oligopolistic firms are faced with similar production costs (i.e. they operate at similar technological levels), the effect of competition upon innovation is greater, and thus the *escape from competition effect* predominates. By contrast, in *unlevelled companies*, or those in which there exists a substantial difference in costs between the leader's lower cost and the follower's higher cost, greater competition can reduce innovation, causing the *Schumpeterian effect* to predominate.

Similar influences exert a greater competition upon efficiency (Berghäll, 2010), although in this case the possibility of an indirect effect is also observable. Competition may harm efficiency via its positive effect

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[4] Fagerberg (1994) and Griffith *et al*. (2003, 2004) also consider that a country's absorption capacity depends on domestic innovation activities.

[5] Crafts (2006) offers a complete survey of regulation and productivity theories. He underlines that deregulation in the European Union was accompanied by a moderate increase in productivity. The theoretical foundations of the relation between competition and growth can be consulted in Aghion and Griffith (2005) and Acemoglu *et al*. (2006).

[6] Chua et al. (2011) study the link between competition and technical efficiency of public hospitals in the state of Victoria. They find a positive relationship between efficiency and competition, as measured by the Hirschman-Herfindahl Index, and a negative relationship when the number of competing private hospital is used instead of that index.

upon innovation: when the innovator is the leader and shifts the frontier, it hinders the approach of followers through efficiency improvements.

As a result of what has been pointed out, a hypothesis of the present study is that the reforms in product markets, centred on liberalisation and deregulation, can affect EC and TC differently, promoting technical change and discouraging efficiency change.

Specification of model [5] is completed by the inclusion of another control variable: the endowments of capital in the ICT (information and communication technologies) sector. This variable allows for the evaluation of the undeniable effect that the development of the ICTs has produced in the EC, as Arnold et al. (2008) propose. This effect is clearly conditioned by the flexibility and capacity shown by the institutional frameworks to adapt to this technological revolution.

III. Sample and data

The sample covers the period 1989-2004 and 15 OECD countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, the United Kingdom and the United States.

The data for Gross Value Added (GVA), physical capital and hours worked were taken from the *EU KLEMS Growth and Productivity Database*. The content and details of the data can be consulted in O'Mahony and Timmer (2009). All the monetary variables are expressed in US dollars at 2000 values.

Using the figures from GVA, physical capital and hours worked, a *sequential* DEA approach was adopted to calculate the indexes TC, EC and MPI expressing them with a base of 100 in 1989. Similarly, the DEA methodology was applied to calculate the distance to the frontier of each country (relative efficiency). These efficiency values are included in the *effscore* variable, which adopts a value of 1 for countries in the technological frontier and a value over 1 to the laggard countries[7].

The estimations used two alternative technological variables: technological stocks and patent stocks, both relative to the GDP of their respective countries. Domestic technological stocks (*stockid*) were established on the basis of private sector expenditure, expressed in the *purchasing power parity* of the US dollar in the year 2000. This variable is available in *Main Science and Technology Indicators* published by the OECD (2009 a). The stocks of each country in year *t* (S^d_t) were calculated using the permanent inventory method, and thus:

$$S^d_t = (1-\delta)\, S^d_{t-1} + R\&D_{t-1}, \qquad [6]$$

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[7] The efficiency of each country is defined according to Farrell's (1957) influential paper. In this context, a country is efficient if it is located on the empirical production frontier which is built from the best practices in the sample. Inefficient countries are those under the frontier. The *effscore* values for each period *t* and country *i* are the values of the distance functions $D_O^t\,(x^t, y^t)$ corresponding to each country. These distance functions (ratio of maximum output to real output) are calculated by solving a standard DEA mathematical programming model similar to those proposed in the Charnes, Cooper and Rhodes (1978)'s seminal paper. The minimum value of these distance functions is *1* and it corresponds to efficient countries. The higher the value of $D_O^t\,(x^t, y^t)$, the greater the distance to the frontier and hence less efficiency. The *effscore* variable is considered in the explanatory models of TFP and EC (see notes below tables 2 and 4 below).

where the rate of depreciation, δ, was assumed to be 0.05[8]. To apply this formula, the stock for the year 1981 was approximated from the expression

$$S^d_{1981} = R\&D_{1981}/(\delta + g) \qquad [7]$$

where g is the average annual accumulative rate of growth in the period 1981–2006. That is to say,

$$g = \ln (R\&D_{2006}/R\&D_{1981})/25 \qquad [8]$$

Concerning the patent stock (*stockpat*), the triadic families published in the *OECD Patent Database* were considered (OECD, 2009 b). These are the set of patents which innovators register in European, Japanese and US offices. They are consolidated data, to eliminate the double counting of patents.

The indicators described in Conway and Nicoletti (2006) were considered to measure the institutional environment. They have approximated the regulation of the non-manufacturing sectors in OECD countries since 1975. These indicators (*etcr*) are centred on the regulations which affect competitive pressures in seven branches of the service sector (airlines, telecommunications, electricity, gas, postal services, railways and road transport), where competition is economically viable[9]. They synthesise information in four main areas: state control, barriers to entry, participation in business operations and, in some cases, market structure.

This piece of research employs the aggregate indicators concerning entry barriers (*enb*), the weight of publicly owned companies (*etcrpo*) and regulatory restrictions in the telecommunications sector (*telecom*). The aggregate indicator of regulation for the seven non-manufacturing sectors above was rejected, as it was not calculated for all the years and countries considered. A more complete description of these institutional variables is presented in section IV.

Finally, *kicth* is another control variable, that is to say, the capital stock in information and communication technologies (ICTs) relative to hours worked. Both variables are taken from the *EU KLEMS* database (2009). The annex contains the simple correlation coefficients of the variables employed in the estimations discussed in the following sections.

IV. Descriptive analysis of the dependent and institutional variables

IV.1 Dependent variables

Table 1 shows the estimates of TFP growth, efficiency and technical change[10]. Note that TFP growth differs from country to country, although there are some common traits. Cross-country diversity in TFP growth is better explained by disaggregating it into its two components. The fifteen countries suffered a decline of 0.6% in efficiency in the period 1990-2004 (on average); technical progress compensated for the negative efficiency change, with an average rate of 1.5%, which made TFP growth possible (of 0.9% per

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[8] This is a similar procedure to that of Coe *et al*. (2009).

[9] The *etcr* indicators cover sectors in which regulation is greatest, given that manufacturing industry in the OECD is minimally regulated and very open to international competition. The range of indicators *etcr* is not as broad as that of the indicators of product market regulation (PMR), also published by the OECD. The indicators *etcr* can also be consulted at http://www.oecd.org/document/32/0,3746,en_2649_37421_35791136_1_1_1_37421,00.html.

[10] Empirical estimations were obtained with the LINGO 11 programming mathematical model solver.

year). TFP growth was high in Ireland, Finland and Sweden; by contrast, Portugal and Spain recorded decreases in average TFP growth, driven largely by efficiency losses. When calculating annual averages, the conclusion is that TFP grew every year except in the period 1991-1993, despite the change in efficiency being positive only in 1990, 1994 and 1995.

TABLE 1.

Total factor productivity decomposition (Period: 1990-2004)

By country	Efficiency change	Technical change	TFP Change	By year	Efficiency change	Technical change	TFP Change
Austria	0.994	1.015	1.008	1990	1.002	1.002	1.004
Belgium	1.000	1.014	1.014	1991	0.997	1.002	0.998
Denmark	0.993	1.015	1.008	1992	0.988	1.010	0.998
Finland	1.001	1.015	1.016	1993	0.989	1.004	0.993
France	0.992	1.013	1.005	1994	1.008	1.014	1.022
Germany	0.997	1.015	1.012	1995	1.012	1.005	1.017
Greece	0.990	1.021	1.011	1996	0.991	1.020	1.011
Ireland	1.011	1.018	1.030	1997	0.990	1.030	1.020
Italy	0.985	1.016	1.001	1998	0.998	1.013	1.012
Netherlands	0.996	1.013	1.009	1999	0.986	1.029	1.014
Portugal	0.980	1.005	0.985	2000	0.979	1.040	1.018
Spain	0.981	1.015	0.996	2001	0.988	1.012	1.000
Sweden	1.000	1.015	1.015	2002	0.988	1.019	1.007
United Kingdom	0.989	1.019	1.008	2003	0.995	1.009	1.004
United States	0.998	1.016	1.015	2004	0.996	1.017	1.013
Geometric mean	0.994	1.015	1.009				
Minimum value	0.948	1.000	0.949				
Maximum value	1.065	1.065	1.066				
Standard deviation	0.017	0.014	0.018				

IV.2 Institutional environment

The most important effects of regulation on productivity are exerted via disincentives to investment and innovation, which reduce the long-run productivity growth rate especially in times of rapid technological innovation. Consequently, product market policies have become friendlier to market over recent decades. Changes have been achieved in most regulatory areas, but have been most spectacular in reducing barriers to entry and, to a lesser extent, regarding public ownership. Likewise, the telecoms sector has experienced substantial reforms, improving competition and spreading positive external effects to the rest of the economy.

Differences in the policy and institutional environment are partly reflected in cross-country productivity patterns. Thus, various stylized facts regarding national differences in how the sampled countries differ in their institutional environment and how these have changed over the period under scrutiny are offered below.

The OECD has published a set of indicators of product market regulation in non-manufacturing sectors in OECD countries[11]. They cover regulations which create barriers to entrepreneurship and restrict

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[11] See Conway and Nicoletti (2006) or OECD (2011).

competition in domestic markets, where technology and demand conditions make competition viable. These indicators cover some of the non-manufacturing industries in which anti-competitive regulation has traditionally been strongest in OECD countries. However, technological advances, the evolution of governance and regulatory techniques, as well as increasing international exposure have made liberalization and privatization increasingly possible in these sectors (Conway and Nicoletti, 2006).

As explained in section III, this paper has selected three indicators which appear to more accurately capture the effects of the deregulation process on productivity growth: barriers to entry (*enb*), degree of public ownership in energy, transport and communication industries (*etcrpo*)[12] and anticompetitive regulation in the telecommunications services (*telecom*), including entry regulation, public ownership and market structure. These three indicators quantify the degree to which regulatory settings are anti-competitive, on a normalized scale from 0 to 6, reflecting the increasing restrictiveness of regulatory provisions to competition. Including public ownership among regulations which hinder competition in some sectors reflects the idea that, with public enterprises often enjoying soft budget constraints and state guarantees, the playing field is not level in the markets in which they operate.

Barriers to entry in ETC (energy, transport and communications) have become less insurmountable by market mechanisms over the years analysed. In 1989, the indicator depicted in Figure 1 suggests that barriers in these sectors were restrictive in all the EU-14 countries (but to a lesser extent in the UK) and higher than in the US. The US is well known to be the first country to begin reforming product markets in the early 1980s. By the end of the period, barriers to entry had been virtually eliminated in the UK, Sweden and Denmark. By contrast, Greece displays the highest level of barriers, followed at some distance by Ireland and Portugal.

Figure 4 shows that the Nordic countries and the UK achieved relatively great reform in 1989-1995. With the exception of Finland and the UK, this reform effort increased with time, the bulk of such reform taking place from the second half of the 1990s onwards.

Comparing Figure 1 with Figure 2 and Figure 4 with Figure 5, the indicators suggest that over the period analysed the reduction of barriers to entry was more dramatic than the decrease in public ownership. In 1989, Figure 2 indicates that the US, followed by the UK, Spain and Germany was the country with the least public ownership in ETC industries. By 2003, these countries also had the least weight of public ownership. At the opposite extreme, Greece, France and Ireland continued to display the highest public ownership. The timing of such reforms (see Figure 5) shows that the most spectacular decrease in public ownership was achieved by the UK. This occurred earlier than in the remaining countries, with the exception of the US (which began its reforms in the early 1980s). Save in the case of Belgium and the Netherlands, privatizations took place more intensively from the second half of the 1990s onwards. The countries which privatized least in 1989-2004 were Greece, France and Ireland, followed closely by Austria.

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[12] Conway and Nicoletti (2006) demonstrate the strong correlation between *etcr* and economy-wide regulation (PMR). They also use alternative regulatory indicators, devised by Gwartney and Lawson (2006) to measure the extent of business regulations and government presence in the business sector. Accordingly, they consider *ectr* indicators to be good proxies for overall regulatory conditions in OECD countries.

Figure 3 shows that regulatory restriction in telecommunications experienced a great decrease in 1989-2003. Most countries reached their highest level of regulation in 1989. The exception is the United States, followed by the UK and Spain. At the end of the period, all countries had reduced their anticompetitive restrictions levels by two-thirds or even more. Finland, Denmark, the UK and the US were the least regulated economies in the telecommunications sector. The timing of reform in this sector is given in Figure 6, which shows that Finland, Denmark and the UK experienced a similar reform effort during the two periods analysed. The remaining countries increased their reform efforts around the turn of the century.

FIGURE 1
Barriers to entry in ETC
(0 to 6 scale from least to most restrictive of competition)

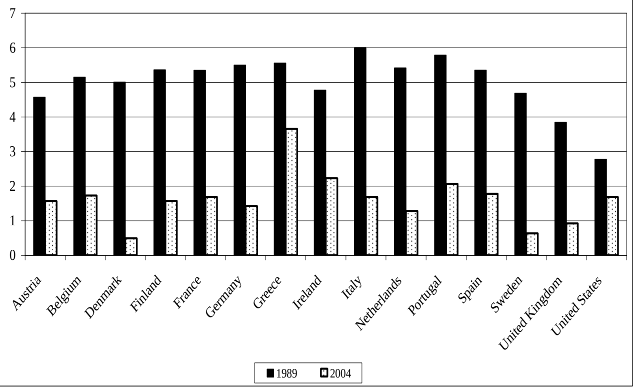


FIGURE 2
Public ownership in ETC industries
(o to 6 scale from least to most public ownership)

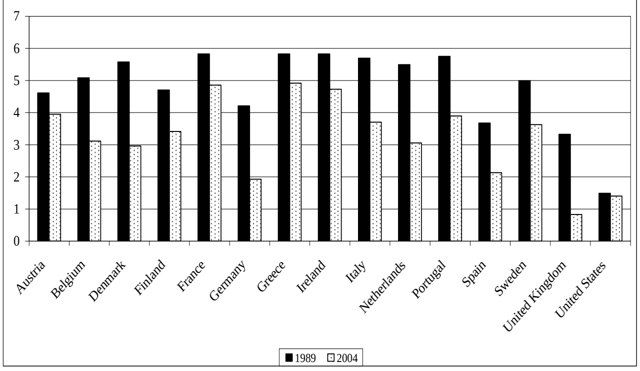


FIGURE 4
Timing of reforms in barriers of entry (enb)
(increasing in reform effort)

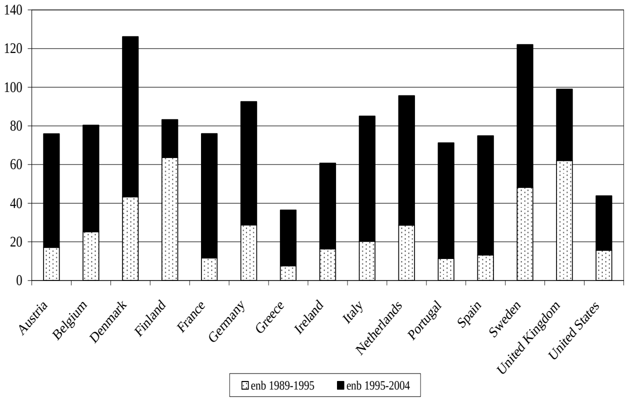


FIGURE 5
Timing of decreasing in public ownership in ETC industries (etcrpo)

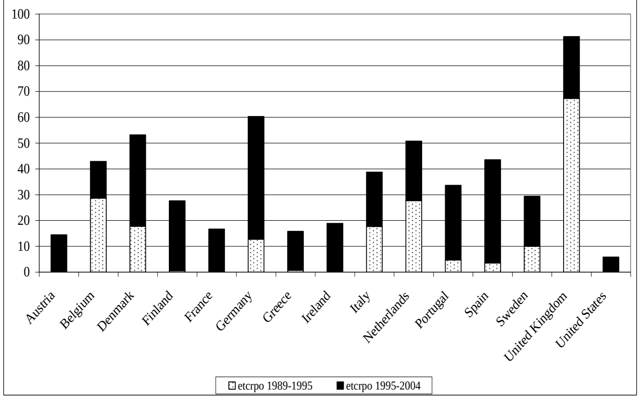


FIGURE 3

Regulatory restrictions in telecommunications

(o to 6 scale from least to most restrictive of competition)

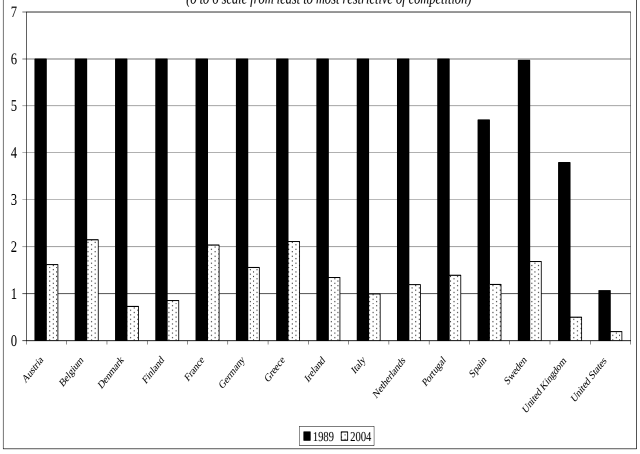
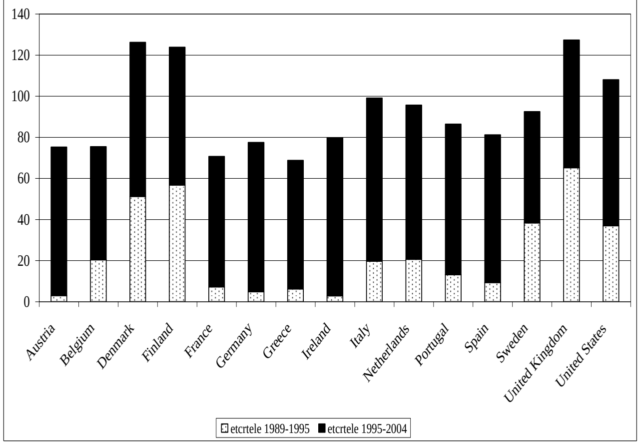


FIGURE 6

Timing of reforms in telecommunications industries (etcrtele)

(increasing in reform effort)



V. Estimations and results

The underlying idea is that the economic relationships among the explanatory variables have a dynamic nature, which can be modelled using dynamic panel data, and that the dynamics in the adjustment processes can be characterised with the lagged endogenous variable as an additional regressor.

The Generalized Method of Moments (GMM) system, developed by Arellano and Bover (1995) and Blundell and Bond (1998) is used in this study. We report results for the one-step system GMM of the STATA statistical software package, following Roodman (2009)[13].

TABLE 2.

Explanatory model of TFP change

	[1a]	[1b]	[1c]	[1d]	[1e]	[1f]
ln (stockid/GDP)	0.457*** (0.112)		0.322*** (0.102)		0.425*** (0.110)	
ln (stockpat/GDP)		0.194*** (0.057)		0.138*** (0.052)		0.187*** (0.057)
*ln (stockid/GDP) * ln (effscore)*	0.919*** (0.209)		1.039*** (0.232)		0.948*** (0.224)	
*ln (stockpat/GDP) * ln (effscore)*		0.305*** (0.098)		0.440*** (0.110)		0.347*** (0.105)
enb	0.005 (0.106)	-0.031 (0.103)				
etcrpo			-0.213** (0.087)	-0.247*** (0.088)		
telecom					-0.059 (0.074)	-0.096 (0.076)
Number of instruments	9	9	9	9	9	9
Number of groups	15	15	15	15	15	15
Arellano-Bond test for AR(2) in first differences	-0.89	-0.98	-0.88	-0.92	-0.91	-0.97
Sargan test	1.58	1.70	2.15	2.16	1.96	2.09

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[13] The *xtabond2* command was employed with the *ivstyle* option (to specify that the technological, institutional and control variables serve as standard instruments), the *gmmstyle* option (with the logarithm of TFP in the explanatory model of TFP change, the logarithm of technical change in the explanatory model of technical change and the logarithm of efficiency change in the explanatory model of efficiency change, and the *lag(2 3) and collapse* suboptions, the *nomata* option (that prevents the use of Mata code) and the *small* option.

Notes: In parentheses are the standard errors. *, ** and *** denote that the variable is significant at 10, 5 and 1%, respectively. *ln (stockid/GDP)* is the logarithm of the ratio between technological stocks and *GDP; ln (stockpat/GDP)* is the logarithm of the quotient of the stock of patents and *GDP*, *ln (stockid/GDP) * ln (effscore)* is the product of the logarithm of the ratio which relates technological stocks to *GDP* by the logarithm of the efficiency level in 1989; *ln (stockpat/GDP) * ln (effscore)* is the product of the logarithm of the quotient of the stock of patents and *GDP* and the logarithm of the efficiency level in 1989; *enb* and *etcrpo* are institutional variables which summarise regulation in the non-manufacturing sector, and specifically barriers to entry and the weight of publicly owned companies, respectively; *telecom* is the indicator of regulation of the telecommunications sector. Estimations were performed adding a set of year dummies.

Table 2 offers the results of the explanatory model of TFP change [equation 3], considering alternative technological variables and indicators of regulation as control variables. The six specifications were performed after adding a set of year dummies. The estimations are accompanied by the Arellano and Bond test to detect the second-order autocorrelation in first differences (Arellano and Bond, 1991). Table 2 shows (as do the following two tables), that it is impossible to reject the hypothesis of no second-order serial correlation in the perturbations. In turn, the application of the Sargan test, to check for overidentification of restrictions in the model, also supports the estimations. Note that the technological variables and their interactions with the distance to the frontier display statistical significance and drive TFP change. However, from among the regulation variables, only *etcrpo* exhibits statistical significance, and a negative sign. This can be interpreted to mean that greater regulation slows down productivity change and, conversely, that increased competition speeds up such change.

Table 3 presents the results of the estimation of the explanatory model of variations in technical change [equation 4], considering six alternative scenarios corresponding to the two technological variables and the three indicators of regulation mentioned above. It should be underlined that the technological variables are statistically significant and drive technical change, showing that this depends on the expenditure accumulated in the country itself or on the set of patents employed in productive processes.

The coefficients which accompany the institutional indicators also exhibit statistical significance, and a negative sign. This allows for the conclusion that the reduction of market entry regulations, the reduction of the relative weight of public companies and the deregulation of the telecommunications sector encouraged technical change. These results provide new evidence regarding the controversial effects of competition upon TFP growth. In this case, the evidence supports the predominance of the *escape effect*, according to which greater competition generates greater innovation for incumbent firms in order to protect or enhance their market position. In line with the conclusions of Aghion et al. (2006), the results of the present study suggest the existence of low average levels of competition in the countries (predominantly with *neck and neck industries*), since it is in this environment where the *escape competition effect* predominates.

TABLE 3.

Explanatory model of technical change

	[2a]	[2b]	[2c]	[2d]	[2e]	[2f]
ln (stockid/GDP)	0.353***		0.268***		0.445***	
	(0.073)		(0.062)		(0.071)	
ln (stockpat/GDP)		0.259***		0.222***		0.284***
		(0.046)		(0.038)		(0.042)
enb	-0.273***	-0.237***				
	(0.0578)	(0.055)				

etcrpo			-0.432*** (0.062)	-0.415*** (0.058)		
telecom					-0.182*** (0.038)	-0.192*** (0.037)
Number of instruments	12	12	12	12	12	12
Number of groups	15	15	15	15	15	15
Arellano-Bond test for AR(2) in first differences	-1.87	-1.74	-1.64	-1.64	-1.71	-1.75
Sargan Test	0.78	0.35	0.38	0.37	0.46	0.50

Notes: Standard errors are in parentheses. *, ** and *** denote that the variable is significant at 10, 5 and 1% respectively. *ln (stockid/GDP)* is the logarithm of the ratio between technological stocks and GDP *ln (stockpat/GDP)* is the logarithm of the quotient of the stock of patents and GDP; *enb* and *etcrpo* are institutional variables which summarise regulation in the non-manufacturing sector, specifically entry barriers and the weight of publicly owned companies, respectively; *telecom* is the indicator of the regulation of the telecommunications sector.

Table 4 presents the results of the estimation of the model explaining the variations in efficiency change [equation 5], taking into account the two technological variables and two control variables: the alternative institutional indicators and the ICT endowments of capital per hour worked. The technological variables, interacting with the distance to the frontier, display statistical significance and stimulated efficiency change. This confirms that technology transfer is a complex process, as a country may benefit from the backwardness advantage only if it has a certain technological capacity, measured here by the stock of R&D or patents, to assimilate the foreign technology and adapt it to local conditions.

TABLE 4.

Explanatory model of efficiency change

	[3a]	[3b]	[3c]	[3d]	[3e]	[3f]
*ln (stockid/GDP) * ln (effscore)*	3.054*** (0.752)		0.374* (0.204)		1.658*** (0.255)	
*ln (stockpat/GDP) * ln (effscore)*		1.829*** (0.432)		0.217* (0.111)		0.918*** (0.140)
enb	7.516*** (2.219)	7.129*** (2.026)				
etcrpo			1.674*** (0.195)	1.669*** (0.195)		
telecom					1.425*** (0.205)	1.414*** (0.203)
kitch	9.221*** (2.472)	8.824*** (2.269)	2.355*** (0.221)	2.350*** (0.220)	2.718*** (0.289)	2.697*** (0.287)
Number of instruments	9	9	9	9	9	9
Number of groups	15	15	15	15	15	15
Arellano-Bond test for AR(2) in first differences	1.87	1.88	-1.50	-1.50	-1.24	-1.24
Sargan test	1.00	1.16	4.42	4.46	0.52	0.57

Notes: In parentheses are the standard errors. *, ** and *** denote that the variable is significant at 10, 5 and 1%. *ln (stockid/GDP) * ln (effscore)* is the product of the logarithm of the ratio which relates technological stocks to GDP by the logarithm of the efficiency level in 1989: *ln (stockpat/GDP) * ln (effscore)* is the logarithm of the quotient of the stock of patents and GDP by the logarithm of the efficiency level in 1989. *enb* and *etcrpo* are institutional variables which summarise regulation in the non-manufacturing sector, and specifically barriers to entry and the weight of publicly owned countries, respectively. *telecom* is the indicator of regulation of the telecommunications sector, *kicth* is a control variable which measures capital endowment in the ICT sector per hour worked.

The importance of the distance to the frontier goes further, since as proposed at theoretical level by Aghion and Howitt (2006) and confirmed at empirical level by Aghion et al. (2006), the degree of development of a country conditions the relation existing among other variables, (such as competition, innovation, entry or efficiency). As the table 3 shows, the increased competition promotes technological changes but it also acts as a disincentive to efficiency improvement for the most backward countries. The latter, faced by remoteness from the frontier and their increase in the technological gap, may abandon efforts to converge. This discouragement behaviour can be explained because the *ex-post* reward that laggard countries obtain for catching up with the technological leader falls as competition intensifies.

This argument may explain why the coefficients of the institutional variables are positive and statistically significant in Table 4. It indicates that deregulation slowed down efficiency change. It was checked, moreover, that the positive signs were maintained when re-estimating the model with the other regulatory variables for six non-manufacturing sectors mentioned above[14].

Finally, the endowments of ICT capital per hour worked exerted a positive and statistically significant impact on efficiency change, as was expected, counterbalancing the effect of deregulation during the years of the ICT revolution.

VI. Comparison with previous studies

The empirical work dedicated to studying the relationships between regulation and innovation presents important differences with our study. These differences refer to the model's specification, the dependent variables, the distance to the frontier variable, the method of estimation and the sample. The most important difference concerns the specification of the dependent variable. Our results make an important contribution to the literature on economic growth, by assessing the distinct effect of independent variables on the two components of TFP growth, innovation (technical change) and imitation (efficiency change) and resolving two common economic puzzles. The first of these is the counter-intuitive and frequently obtained result of the non-significant or positive influence of anti-competitive regulation variables on productivity growth, as is the case in some specific versions of the models of Aghion et al. (2009), Conway et al. (2006), Nicoletti and Scarpetta (2003), Inklaar et al. (2008), or Buccirossi et al. (2009). The second puzzle refers to the non-significant or negative influence of research intensity on productivity growth that is obtained in some specifications such as in the work of Saxena et al. (2008), Ulku (2007b), Islam (2009), Madsen (2008) or Barcenilla et al. (2011).

Our study offers a response to these ambiguities by distinguishing innovation and efficiency change as dependent variables: product market regulation and technological research prove to be undoubtedly significant, but with different signs or different specifications, depending on which component of TFP is being explained.

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[14] Although this study does not include the results of these specifications, as there were detected problems of second-order (the Arellano-Bond test) and/or the instruments employed (the Sargan test).

a) Research intensity boosts innovation

The positive and significant sign of the research intensity variables on innovation provides evidence in favour of the *direct* effect of the technological variable upon a country's or sector's rate of innovation. This is the case of the sectoral works of Zachariadis (2003), who uses data for a panel of USA industries for the period 1963-1988 and shows that R&D intensity has a positive impact on the rate of patenting. Ulku (2007a) finds that the influence of R&D intensity (the ratio of company R&D expenditure to output) on the rate of innovation (the flow of patents) is positive and significant in three of the four manufacturing sectors of 17 OECD countries over the period 1981-1997. Ulku (2007b) uses the ratio of the share of researchers in the total labour force to proxy research intensity and finds that the coefficient is significant, although only for large market OECD countries. Our results are also in line with Maudos et al. (2000), who break down the contribution of technical change, efficiency change and the accumulation of inputs per worker to the growth of labour productivity. They demonstrate that technical change has been an important source of divergence in the labour productivity of OECD countries over the period 1975-1990.

b) Research intensity encourages imitation

Our paper offers empirical evidence that technology plays a role beyond the stimulation of innovation, namely that of facilitating imitation. The positive and significant sign of the interaction variable in Table 4 is representative of the importance of absorptive capacity in the process of catching up, and of the indirect effect of technology on TFP growth. The further a country lies behind the frontier, the greater is the potential of research intensity to accelerate this process, through the transfer of technology.

Although not directly comparable, our results are in line with those of Griffith et al. (2003, 2004) and Madsen et al. (2009). Using a panel of industries of 12 OECD countries, the former observe that R&D affects the rate of cross-country convergence in productivity growth. According to Madsen et al. (2009) the estimated coefficients of the interaction between research intensity and distance to the frontier are significant for the developing countries but, consistent with the estimates of Madsen (2008), not for OECD countries. So, in contrast to developing countries, R&D in OECD countries enhances productivity growth but does not boost absorptive capacity. This dual behaviour, observed in developed *versus* developing countries is the same that can be seen between leaders and followers in this peper. In both cases, the results provide support for the Schumpeterian growth models of Howitt (2000), Howitt and Mayer–Foulkes (2005) and Griffith et al. (2003).

c) Competition boosts innovation

Our results reinforce the common wisdom in the economic literature, namely that PMR (product market regulation) curbs innovation by limiting the intensity of competition. In contrast, product market deregulation, and hence increased competition, produce an “escape competition effect” which shifts the frontier as shown by Geroski (1990), Nickell (1996), Blundell et al. (1995, 1999), Carlin et al. (2004) or López Pueyo et al. (2008).

This *direct* positive effect of economic liberalization upon innovation confirms the results obtained by other authors. Barbosa et al (2011) rely on a cross-section of 22 manufacturing industries in 10 EU countries and demonstrate that institutions have a negative effect on the intensity of innovation in 10 of them. Griffith et al. (2010) regarding the markets of 9 EU countries and 12 manufacturing industries over the period 1987-2000, providing empirical evidence that the reforms undertaken under the EU Single Market Programme (SMP) were associated with increased product market competition and with an increase in innovation intensity and productivity growth for manufacturing sectors.

These results also corroborate the findings of Amable et al. (2009) for a sample of OECD countries over the period 1979-2003. In most regressions of their model the direct effect of the regulation indicator on innovation is negative and significant.

d) Competition discourages imitation

Our results in Table 4 support the argument that more competition, resulting from a deregulation process, causes a “Schumpeterian effect” in follower countries discouraging imitation. As seen above, deregulation encourages the shifting of frontiers and makes it more difficult for followers to catch up.

The positive relationship between anti-competitive policies variables and efficiency change can be compared with the conclusions obtained in different studies in relation to the process of catching up. Most of the studies referred to above introduce an interaction term between the technological gap and a PMR variable to distinguish the mixed effect of regulation, depending on the distance to the frontier. Our results do not support the interpretation of Nicoletti and Scarpetta (2003) and Conway et al. (2006), both of whom interpret that a positive coefficient for the interaction terms between PMR indicators and *the inverse* of the technology gap as evidence in favour of the perverse effect of regulation that slows down the process of catch-up. Firstly, the process of catching up depicted in Table 4 is not automatic, but rather requires complementary factors such as a technological stock sufficient to absorb technology. Secondly, the process of deregulation slows down catching up, measured by the efficiency change in Table 4: the lower are *enb*, *etcrpo* and *telecom*, the slower is catching up to best practice technologies.

Our results are in line with the evidence offered by Aghion et al. (2009). In their work the estimate of the interaction term between PMR and the distance to the frontier variables shows a positive sign for countries far from the frontier and a negative sign for countries close to the frontier. This result indicates that, with the exception of the public ownership variable, the reducing of product and market rigidities increases TFP growth for countries near to the frontier but undermines TFP far from the frontier.

VII. Conclusions

The importance of TFP in explaining economic growth and the differences observed in it among nations in recent decades have motivated studies aimed at providing evidence of its components and determinants. This study deepens this research area by calculating TFP through the Malmquist index, disaggregating its change into two components, technical change and efficiency change, and explaining each component separately with an empirical model.

The empirical evidence provided for 15 OECD countries and the period 1989-2004, allows for the conclusion that technical change was driven by accumulated domestic technology and by institutional measures aimed at the deregulation of economic activity. In turn, domestic technology also promoted efficiency change through the absorptive capacity of the latecomer countries, but in contradiction to the result obtained for technical change, was slowed down by deregulation.

The comparison of our results with previous studies is conditioned basically by the nature of their dependent variable, their measurement of the proximity to the frontier and their interaction with the regulation indicators, as well as the difference in the aggregation level of the sample. We consider that the effects of technological capital and deregulation on TFP growth should be measured with more accurate dependent variables, using total factor productivity change decomposed into technical change (innovation) and efficiency change (imitation). Furthermore, the distance to the frontier should be measured as the efficiency score obtained from a DEA analysis, because labour productivity relative to the frontier neither measures the productivity of other production factors nor measures the efficiency position of a country by considering the frontier relative to a similar mix of production factors (as DEA does). This is an important issue, because the results are conditioned by how closeness to the frontier is measured. We consider that our model specification is more appropriate to evaluate the role of the regulation environment and the distance to the frontier. In our specification, the role of regulation in innovation and the role of regulation in the process of catching up (imitation) are captured separately.

Our research demonstrates that the effect of factors that enhance the technological growth changes with distance. Technological intensity, has a direct effect on innovation but an indirect one on imitation. In other words, R&D is innovative in leader countries which make leading-edge innovations, but is predominantly imitative in follower countries, where innovation is simply the implementation of technologies developed elsewhere. This latter effect operates by augmenting the *absorptive capacity* of followers: the growth-enhancing effect of technological intensity increases with distance to the frontier.

This result provides evidence in favour of the Schumpeterian framework, which incorporates Gerschenkron´s *advantage of backwardness* in the sense that the further a nation is behind the frontier, the faster it will grow. This advantage arises from the fact that imitations allow such countries to make larger quality improvements the further they have become distanced from the frontier.

Our paper also has important implications in relation to Schumpeterian theories which emphasize that the relative position -leader versus follower- of a country conditions growth dynamics. *Appropriate institutions and policies* to promote growth are not the same, depending on the distance to the frontier. Anticompetitive policies have different effects on innovation and on imitation. Regulation hinders the former but boosts the latter. Leaders' innovation makes it more difficult for laggards to catch up, thereby slowing down the process of imitation.

The model estimated offers empirical evidence regarding the debate on the effects of greater competition upon TFP. Concretely, the results of these effects defend the predominance of the so-called *escape competition effect* on technical change, and of the S*chumpeterian effect* on efficiency change. We therefore offer empirical support to the proposal made by Aghion et al. (2005) concerning the existence of an inverted-U relationship between competition and innovation. We hope that these results contribute to the open debate over regulation (innovation and catch-up), indicating the importance of measuring these variables and specifying their relationship.

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ANNEX

Correlation coefficients for the variables employed in estimating the models

	Δ ln (TFP)	Δln(T)	Δln(E)	ln(stockid/GDP)	ln(stockpat/GDP)	ln (stockid/GDP) *ln(effscore)	ln (stockpat/GDP) *ln(effscore)	etcrpo	enb	telecom	kitch
Δ ln (TFP)	1.00	0.47	-0.13	0.24	0.31	0.15	0.15	-0.02	-0.20	-0.08	0.17
Δ ln (T)		1.00	-0.32	0.07	0.06	0.12	0.12	-0.19	-0.30	-0.33	0.22
Δ ln (E)			1.00	0.20	0.28	0.06	0.07	0.13	0.02	0.17	0.00
ln (stockid/GDP)				1.00	0.87	-0.57	-0.55	-0.47	-0.53	-0.32	0.49
ln (stockpat/GDP)					1.00	-0.35	-0.32	-0.35	-0.51	-0.21	0.38
ln (stockid/GDP) * ln (effscore)						1.00	0.99	0.40	0.27	0.25	-0.25
ln(stockpat/GDP)* ln (effscore)							1.00	0.39	0.25	0.24	-0.24
etcrpo								1.00	0.68	0.74	-0.55
enb									1.00	0.87	-0.73
telecom										1.00	-0.68
kitch											1.00

Notes: Δ *ln (TFP)* is the TFP change; Δ *ln (T)* is technical change; Δ *ln (E)* is efficiency change; *ln (stockid/GDP)* is the logarithm of the ratio which relates technological stocks to GDP; *ln (stockpat/GDP)* is the logarithm of the quotient of the stock of patents and GDP; *ln (stockid/GDP) * ln (effscore)* is the product of the logarithm of the ratio which relates technological stocks to GDP by the logarithm of the level of efficiency in 1989; *ln (stockpat/GDP) * ln (effscore)* is the logarithm of the quotient of the stock of patents and GDP by the logarithm of the level of efficiency in 1989; *etcrpo* and *enb* are institutional variables which summarise the weight of publicly owned companies and the barriers to entry, respectively; *telecom* is the indicator of regulation of the telecommunications sector; *kicth* is a control variable which measures the endowment of capital in the ICT sector per hour worked.