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International technology diffusion through patents during the second half of the XXth century*

Antonio Cubel, Vicente Esteve and M. Teresa Sanchis**

Abstract

This paper analyzes the impact of domestic and foreign technology in explaining Total Factor Productivity (*TFP*) growth during the second half of the 20th century in some advanced countries (the U.S., France, Germany, the U.K. and Japan). To carry out this objective we use new dataset for the stock of knowledge built on the basis of the Perpetual Inventory Method over patents data for 150 years. To empirically address the aim of this research, we extend Coe and Helpman (1995) empirical specification by including human capital. Our results point out that: first, both domestic and foreign stocks of knowledge are significant in explaining *TFP* growth; second, the imports of knowledge have a less significant effect than the domestic stock of knowledge for France, Germany and Japan. Further, our results point that human capital plays a superior role in explaining TFP growth in the most advanced countries.

Keywords: Europe, second half XXth century, international technology transfer, patent, productivity, cointegration techniques.

JEL Classification: N14, O33, O47, O22.

Resumen

En este trabajo se analiza el efecto de la tecnología doméstica y extranjera en la evolución de la Productividad Total de los Factores (PTF) para una muestra de países avanzados (Estados Unidos, Francia, Alemania, Reino Unido y Japón) durante la segunda mitad del siglo XX. Para ello se construye una base de datos en la que se mide la tecnología, tanto doméstica como importada, a través de las patentes acumuladas desde 1850 siguiendo el método del inventario permanente. Empíricamente, se estima una versión ampliada de la especificación de Coe and Helpman (1995) en la que incluye la variable capital humano. Los principales resultados permiten concluir que: primero, que tanto la tecnología doméstica como la importada son significativas en la explicación del crecimiento de la PTF; segundo, que las importaciones de tecnología tienen un efecto menor sobre la PTF que la generación doméstica de tecnología en países como Francia, Alemania y Japón, mientras que en Estados Unidos sólo es significativa la tecnología doméstica. Y por último, los resultados revelan una elevada contribución del capital humano en la explicación de la PTF de los países más avanzados.

Palabras clave: Europa, segunda mitad del siglo XX, transferencia internacional de tecnología, patentes, productividad, técnicas de cointegración.

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1. Introduction

The catch-up theory holds a prominent position for the explanation of economic growth during the second half of the XXth century. Its realization explains growth during the Golden Age and its exhaustion is behind the subsequent slowdown after the oil shock. Additionally, more comprehensive explanations tend to assign a superior role to the development of “social capabilities” in Europe, and also in Japan, that provided an endogenous stimulus to innovation during the Golden Age but that loosed weight after the seventies. These capabilities were related to the stimulus for investment in the context of a new international order more open to competition and trade. The new arrangements increased the investment rates not only in physical capital but also in innovation and human capital. One relevant question to the understanding of the catch-up hypothesis refers to how technological progress entered into European countries, and whether there is room for technological spillovers throughout trade in capital and intermediate goods.

During the last two decades developments in economic growth theory have emphasized the importance of commercially oriented R&D efforts as an engine for growth. Firstly, some models predict that labour productivity and TFP are positively related to the stock of domestic R&D capital (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992). A common feature of these models is that they assume the existence of knowledge spillovers effects and, as a logical consequence given the level of domestic R&D effort, they assume that a process of opening up and integration of formerly closed economies will tend to raise their growth rates (Rivera-Batiz and Romer, 1991). From these models, an important amount of empirical works have emphasized the importance of both domestic R&D efforts and international technology spillovers in explaining national productivity growth and the complementarity between R&D and human capital investments.

Empirical evidence in favour of the role of international technology diffusion was first put forward by Coe and Helpman (1995), henceforth CH, who presented an empirical model based on the endogenous theories of economic growth that treat commercially oriented innovation efforts as major engines for technological progress. CH empirical evidence showed that TFP growth for a country depends on its own R&D efforts and on foreign R&D that spills over into the world economy by means of trade. They concluded that trade was an important mechanism through which knowledge and technological progress was transmitted in the OECD countries.

Following CH model, we can find three relationships that have been vastly studied in the empirical literature of economic growth. The first one refers to the role of the domestic technology effort. This has been well established in different pieces of research. There is a wide consensus in considering that the productivity effect from domestic R&D is stronger than that from foreign R&D in large countries, whereas in many smaller countries the elasticity is larger with respect to the foreign R&D capital stocks.

The second relationship refers to the role of trade in the diffusion of technology. It should be noted, that an extensive literature still questions the relative importance of trade in the transmission of knowledge between countries. The role of trade for transmitting knowledge was firstly analysed by CH, who concluded that R&D produced *into* the trading partners spread to other countries by means of bilateral trade. The above conclusion was questioned afterwards by Keller (1998) who showed that the imports shares in the construction of the foreign R&D variable are not essential to obtain CH results. From these results Keller (1998) concluded that the direction of trade does not matter or at least it had not been convincingly demonstrated in CH work.

Since then a branch of the literature has tried to test the role of trade in the diffusion of foreign technology. Xu and Wang (1999), for example, have found that technology diffusion is more directly associated with differentiated capital goods trade than to overall trade, as done in CH. More recently Lumenga-Neso et al. (2005) strengthen again the view that trade does matter for the international transmission of knowledge because both "direct" spillovers (R&D generated into the exporter country) and "indirect" trade-related spillovers (foreign R&D experienced by the exporter country) are positive and significant in explaining TFP growth. Madsen (2007) arrives to similar conclusions with a dataset of technology imports over 135 years for the OECD countries.

Finally, the third relationship refers to the role of human capital. Since the work of Engelbrecht (1997), who introduced human capital variables in these R&D models, several studies incorporate improved measures of human capital in the analysis[1] and most of them confirm a clearly net significant and positive impact of human capital on productivity growth.

In line with the above literature, in this work we analyse how the evolution of the TFP of the most advanced European countries, Japan and the U.S. during the second

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[1] For example: Frantzen (2000), Barrio-Castro *et al* (2002) …

half of the XXth century depends on the domestic innovative efforts, on the foreign innovative efforts that spills over into the world by means of trade and on the development of social capabilities measured by means of the human capital variable. We consider that studying this relationship is particularly appealing for several reasons. First, during these decades barriers to trade between countries were significantly reduced and new institutional arrangements improved the economic cooperation between countries. In this context, new opportunities for spill over technology between trade partner countries arose and it has been a prominent hypothesis in the explanation of growth in the Golden Age period[2]. Second, the countries considered (Japan, France, UK, Germany) were among the most developed countries in the world and had an endogenous capacity for benefiting from importing foreign technology.

In this research we estimate the technology diffusion model introduced by Coe and Helpman (1995) and extended by Engelbrecht (1997) for France, Germany, United Kingdom, the U.S. and Japan separately, through a long period of time (over 50 years) by using cointegration time series techniques. A relevant contribution of our work to the existing literature is the consideration in the analysis of data for the Golden Age period, when the western countries and Japan reached the highest rates of output and productivity growth and closed most of their technological gap with the US. We consider that it is important to include these decades as, up to date, published pieces of research on this subject start the analysis of technology transfer some years later (mid 60s), just when most of the catch-up process has been accomplished. This is so because data on R&D stocks are available only since 1965. We consider that it might be crucial, for the analysis of international technology diffusion, to start just at the beginning of the 50s in order to account for the catch-up process, as much as possible. For this purpose, we construct an alternative measure to R&D stock to measure technology diffusion. Particularly, we build a stock of patents index that would be used as an indicator for innovation and technology diffusion[3]. Relative to R&D stock, patents data have been collected for a longer period of time (more than 150 years for some countries).

The results we find in our work are in line with the existing literature. First, we can conclude that there is a robust long run relationship between international technology diffusion and TFP growth. Second, the arrival of international technology throughout trade is important for explaining the evolution of TFP growth in Europe and

[2] Many economists and historians considers that the reduction of trade barriers in the post-war world lead to an era of globalization and that this globalization was an important factor in the explanation of convergence in the more developed countries (for example, O'Rourke and Williamson, 1999).

[3] The stock of patents has been recently used by Madsen (2007), as an indicator of technology diffusion, for a sample of 17 countries over 150 years.

Japan, although we cannot assert that this is also true for the U.S. And, third, and more important, our results confirm that for all the countries considered the role of domestic innovation is higher than the role of the international spillovers of technology.

The rest of the paper is organized as follows. In the second section, we review the historical background for explaining growth during of the Golden Age and the subsequent period of slowdown in productivity growth. In the third section, we describe the model, the data collection and some descriptive statistics of the main variables in the study. In the fourth section, we report the estimation results of the model. Finally, section fifth concludes.

2. Historical background: the relative role of international R&D spillovers

The economic history of Europe during the half century following the end of the Second World War is usually subdivided into two distinct periods, the first, to about 1973, being characterized by very high growth rates and, the second, showing a rather sluggish performance in terms of output and productivity[4]. Table 1 shows that while the US GDP growth slowed down from 3.96 percent (on average per year from 1950-1973) to 3.10 percent (for the period 1974-2000), the decline in some European countries and Japan was even bigger. In particular, the GDP growth declined from rates of 5.05 to 2.26 percent for France, from 6.02 to 2.00 percent for Germany and from 9.32 to 2.83 percent for Japan. The UK represents an exception due the lower growth rates experienced during the whole Golden Age period. The same pattern can be observed in GDP *per capita* growth rates and TFP growth. Growth accounting exercises outline that TFP growth is the main source for the acceleration of growth during the Golden Age and for subsequent slowdown in the post-oil shock era.

These growth rates allow identifying different periods of convergence and divergence, with respect to the US income level. In Figure 1, we plot country convergence, defined by country GDP *per capita* expressed as a percentage of the US GDP *per capita*. This indicator represents, relatively well, the idea of catching-up as a result of technology diffusion. In the figure it is possible to observe a clear period of fast convergence during the Golden Age that came to a halt at the middle of the 1970s, when

[4] Different authors has been investigated this issue, by following diverse methodologies, trying to find a relationship between time and the growth rate (Crafts and Mills, 1996; Fagerberg and Verspagen, 2002). More recent classification considers three sub-periods because of the highly rates of growth during the second half of the 1990s (Ark, O'Mahony and Timmer, 2008; Jorgenson, Ho and Stiroh, 2008).

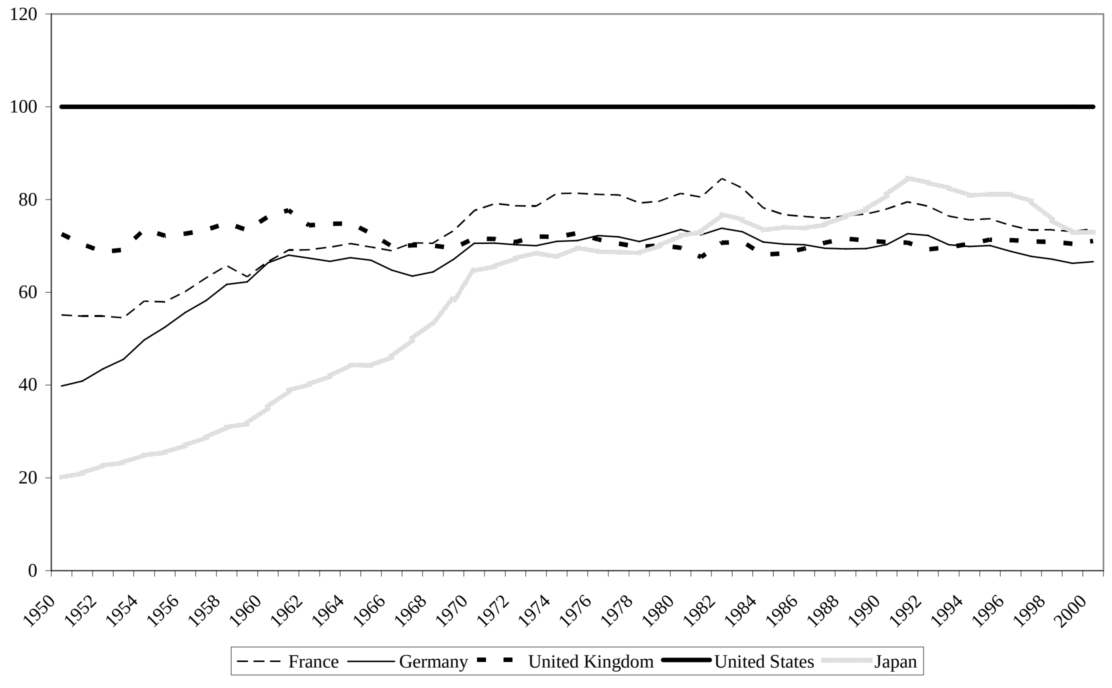
Table 1
Average Annual Growth Rates of GDP, GDP per capita and TFP, 1950-2000

	France	Germany	United Kingdom	United States	Japan
GDP					
1950-1973	5.05	6.02	2.94	3.96	9.32
1974-2000	2.26	2.00	2.17	3.10	2.83
GDP *per capita*					
1953-1973	4.05	5.03	2.43	2.48	8.09
1974-2000	1.75	1.81	1.95	2.01	2.25
TFP					
1953-1973	4.47	3.02	1.60	3.88	5.49
1974-2000	1.14	0.80	1.66	3.57	0.93

Source: Calculations based on the Conference Board and Groningen Growth and Development Centre. Total economy Data base, January 2009 at http://www.conference-board/economics/

the growth trend started to slow down. Only Japan continued the convergence with respect to the US until the 1990s. The U.K. seems to be a different case, with a relative decline in output in relation to the U.S. during the Golden Age and a more favourable behaviour during the last decade of the XXth century.

Figure 1
Converge trends with the US (GPD *pc* as a percentage of the US GDP *pc*)



Source: Groningen Growth and Development Centre, total economy database.

Hence, the Golden Age emerges as a distinctive period of high growth rates and clear convergence with the lead country, the U.S. In contrast with the above conclusion, the period after 1973 appears as one of stagnation in output and productivity growth and as a period of no convergence with relation to the U.S. This particular stage of economic growth, for the most advanced economies, has been explained in different ways. Most of the explanations emphasize that the economic conditions in that period created a special environment for demand stability that boosted investment and fostered economic growth after the World War II. Other studies have pointed that the greater ease of technology transfer, relative to the period before the WW II, was behind the reduction of the technological gap with the U.S. and that this fact is a consequence of the dramatic reduction of trade barriers in the post-war world, specially between the industrialized countries, as evidence by the dramatic rise in intra-European trade during the 1950s and the 1960s[5].

The period immediately after the WWII is considered as a period in which a set of innovations, jointly characterized as "mass production", diffused through the economies of the developed world. These technologies were pioneer in the US during the first half of the 20th century, in the form of the Henry Ford assembly belt and organizational innovations around this, and jointly with a bunch of new products and processes arising from the use of oil, electrification and new raw materials.

The origin of the post-war technological gap has been addressed by a great deal of historical analyses[6]. Nelson and Wright (1992) consider that the advantages developed since the last quarter of the nineteenth century in the U.S. rested on its wide market size, the abundance of natural resources and on the great effort in higher education and in investment in research and development. These factors constituted an incentive to innovation in the U.S., and as a consequence, a wide variety of sectors took advantage from these innovations[7] and provided a big comparative advantage to the U.S. with respect to the European countries. Although some European countries begun to experiment with mass production technologies before the war (like the U.K. or Germany), Nelson and Wright (1992) consider that the European countries could not take advantage from the U.S. innovations as they were particularly tailored to the resource endowments and market dimensions of the U.S. However, the decline in

[5] Epstein, Howlett and Schulze (2007) reveal the importance of the formation of trade partner groups for explaining growth during the Golden Age, but that does not seem to work in the same direction during the post-Golden Age period.
[6] See, among others, Rosenberg (1981), Abramovitz (1986, 1989), and Nelson and Wright (1992).
[7] See for example Chandler (1990), Sokoloff (1988), Rosenberg (1981), Wright (1990). For the boom of the new sectors in the U.S. economy before the WWII see Field (2003 and 2006).

transport costs and trade barriers after WWII contributed to a rapid growth of domestic and international markets in Europe, and allowed the development of economies of scale and capital intensive technologies also within Europe (Nelson and Wright, 1992).

More important than the extension of the size of the market or the access to cheaper natural resources was the development of "social capabilities" to adopt these technologies (Crafts and Toniolo, 1996). Economic agents (government, entrepreneurs, workers) were aware both of the enormous potential for growth involved in importing technologies from the most advanced countries, and of the need to develop "social capabilities" for adapting them in the recipient countries. As a proof of this fact, we can mention the productivity missions sent to the U.S. or invited by this country that tried to emulate the American prosperity (Glyn et al., 1990). In Japan, after the WWII the technology policy was intensified and the government put strong impetus to promote imports of the best technology in the world and whenever possible to adapt and to improve it. These efforts were together with an identification of education and training as key factors of modernization (Freeman, 1987).

The new international order created after the war played a crucial role for inducing both entrepreneurs and workers to change towards innovations. In the post war settlement two mutually reinforcing parts can be distinguished: one international and the other one domestic. The high investment ratios that characterized the Golden Age rested on, more or less, explicit social pacts aimed at increasing productivity, whereby workers exercised wage moderation on the understanding that capitalists would invest their profits into the productive process (Eichengreen, 1996 and 2007). The international setting was crucial in these two respects. On the one hand, it made the pact appealing by guaranteeing a minimum standard of living during the early post-war years, through the Marshall Plan and the European Payments Union. On the other hand, it created an environment characterized by stability, for both domestic prices and exchange rates (Boltho, 1982), and by a growing international trade (Helliwell, 1992; Ben-David, 1993). These characteristics made agents confident about the real value of their incomes as well as about their future increases. Olson (1982) stress that the new arrangements after the World War II, such as trade liberalization and the formation of the European Community weakened the groups of interest formed through time and reduced barriers to investment in new technologies.

In this paper we use the extended Coe and Helpman (1995) specification to explore the role played by changes in the international technology diffusion measured throughout the stock of foreign patents and diffused throughout trade; and, the role of domestic efforts for developing new technologies, in the explanation of productivity growth in the most advanced countries during the second half of the XXth century. To measure the domestic efforts we will use two variables: the stock of patent generated by the residents and a variable for human capital. These two variables jointly represent the capacity for generating innovations into the country and are directly related with the development of conditions that made competition more credible and investment for increasing productivity more necessary.

3. Empirical framework

The empirical model used in our empirical analysis is the model proposed by CH and extended by Engelbrecht (1997) by adding a human capital. This model can be represented as follows:

$$\log TFP_{it} = \alpha^0 + \alpha^d \log S_{it}^d + \alpha^{mf} m_{it} \log S_{it}^f + \alpha^H \log H_{it} + \varepsilon_{it} \qquad (1)$$

where TFP_{it} is total factor productivity for country i and year t, S_{it}^d is the stock of domestic patents, S_{it}^f represents the imports of technology, *mit* is the propensity to import (measured as the fraction of imports to GDP), H_{it} is the domestic stock of human capital and ε_{it} is a disturbance term. The model is estimated both with and without m.

In what follows we describe the procedure taken to calculate each of the variables that enter in the model.

3.1. Measurement of total factor productivity

The construction of *TFP* uses a homogeneous Cobb-Douglas technology function, where the factor shares are allowed to vary over time and across countries:

$$TFP_{it} = \frac{Y_{it}}{K^{\beta_{it}} * L^{(1-\beta_{it})}} \qquad (2)$$

where Y_{it} is real *GDP,* K_{it} is capital stock, L_{it} is employment and β is the share of capital in total income. To calculate TFP_{it} we take the value of β from the *Groningen Growth Development Centre* (*GGDC*) *Database. GDP* is calculated at 1985 *PPP* and expressed in millions of 1985 international US dollars[8]. The original series for *GDP* come from the *GGDC* database[9] and have been converted into constant 1985 *PPPs* taking as benchmark GDP data elaborated at the phase V of the *International Comparison Project* from the United Nations (1994).

Capital stock is taken from O'Mahony (1996). This dataset contains homogeneous capital stock series since 1950 for five countries: United Kingdom, France, Germany, United States and Japan. This limitation in the availability of capital series since 1950 has restricted our analysis to only these five countries. The capital stock is computed as machinery and equipment capital stock plus non-residential buildings and structures capital stock.

Total employment is taken from the *GGDC* database. In this database the labour income share is calculated as the economy-wide compensation to employees divided by nominal *GDP*, where compensation is corrected for imputed payments to the self-employment. This data set provides figures for every year since 1950 for USA and Germany, and for 1950 and from 1955 onwards for the remaining countries (UK, Japan and France). With the aim to cover the previous years (1951-1954) for the UK, Japan and France we have assumed that employment grew at the same rate as population for those years.

The human capital data variable is taken from Morrisson and Murtin (2008) who made the important contribution of building series of average years of schooling in 74 countries for the period 1870 to 2010. For the period 1870-1960 Morrison and Murtin have constructed original series from census information and for the period 1960-2010 they have taken the Cohen and Soto (2007) database. As the Morrisson and Murtin database provides average years of schooling of the active population every ten years we have used De la Fuente and Doménech (2006) data base for making interpolations every five years and hence building annual series of educational attainment.

3.2. Knowledge stock

The measures we use for domestic and foreign stock of knowledge are based on patents statistics. Patent data come from the *World Intellectual Property Organization (WIPO) Statistics Database*. We use patents applied by residents instead of patents

[8] The choice of 1985 as the benchmark year aims to be consistent with O'Mahony (1996) international comparable series of capital stock. This constitutes the unique database that offers homogeneous series of capital stock since 1950.
[9] See the web page http://www.conference-board.org/economics for details on the data provided.

granted. For international comparisons, the number of patents applications, is probably a better measure of the innovative activity than the number of patents granted because the granting frequency varies across countries (Griliches, 1990). For each country we have calculated the domestic stock of patents series and the imports of knowledge.

It is widely accepted that patents are a reliable indicator for the innovative activity when there is not appropriate data on R&D[10]. Therefore, it has become a standard practice to use patent statistics for monitoring innovative activities and the development of new technologies. However, when using patent statistics as an indicator of inventive activity, the following issues should be taken into consideration[11]. First, not all inventions are patented. This is so as there are other alternatives, such as trade secrecy or technical know-how, available to inventors for protecting their inventions. Second, a small number of patents accounts for most of the value of all patents. This means that simple patent counts could bias the measure of technology output. Third, patent systems for protecting inventions vary across countries and industries. Fourth, applicants' different filing strategies or filing preferences may make direct comparisons of patent statistics difficult across countries. A large set of innovations is not ever patented. Fifth, differences in patent systems may influence the applicant's patent filing decisions in different countries. Sixth, due to the increase in the internationalization of R&D activities, R&D may be conducted in one location but the protection for the invention might be done in a different one. And, finally, cross-border patent filings depend on various factors, such as trade flows, foreign direct investment, market size of a country, etc.

Notwithstanding the points mentioned above, patent statistics provide valuable information about a country innovative activity. Relative to other measures of technology, patents have the advantage that data have been collected for a long period of time (more than 150 years for some countries), and for a vast number of countries, including poor countries. For our research we find that using patents, as an indicator of the innovative activity of a country, has a clear advantage over using a measure of a country R&D (the obvious alternative to patent data), as the series on internationally comparable country R&D are only available from the OECD since 1965. However, using patent data we can extend the time span of our investigation until the beginning of the 1950s.

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[10] Schmookler (1966), Griliches (1984, 1990) Griliches, Pakes and Hall (1987), Schankerman and Pakes (1986), Jaffe, Trajtenberg and Fogarty (2000), Dernis, Guellec and Van Pottelsberghe (2001).
[11] Dernis, Guellec and Van Pottelsberghe (2001) and Griliches (1990).

The domestic stock of patents has been calculated from annual patent data based on the perpetual inventory method. The formula of the stock is:

$$S_{it}^{d} = (1-\delta)S_{it-1}^{d} + p_{it} \tag{3}$$

where S_{it}^{d} is the patent stock for country *i* in year *t*, p_{it} is the number of new patents in for country *i* year *t* and δ is the depreciation or obsolescence rate, which was assumed to be 5 percent[12]. The initial value for the stock of patents was calculated employing the perpetual inventory method (PIM).

To measure the technology spillovers embodied in trade flows we estimate two measures of the imports of knowledge which differ in their weighting procedure. The first one follows CH aggregating procedure ($S_{it}^{f,CH}$):

$$S_{it}^{f,CH} = \sum_{j} \frac{m_{ijt}}{m_{it}} S_{jt}^{d} \tag{4}$$

where m_{ijt} is the flow of imports of goods and services of country *i* from country *j* in period *t*; m_{it} is the total imports of country *i* from its trading partners in *t*. This formulation assumes that a country will reap, *ceteris paribus*, more international R&D spillovers if the country imports more from countries with a relatively high domestic capital stock.

Lichtenberg and Van Pottelsberghe de la Potterie (1998) criticize this method of aggregation due to its sensitivity to the level of data aggregation that makes it highly volatile[13]. Their alternative measure is:

$$S_{it}^{f,LP} = \sum_{j=1}^{17} \frac{m_{ijt}}{y_{jt}} S_{jt}^{d} \tag{5}$$

where y_{jt} is country *j GDP* in *t*. According to this measure, a country will reap, *ceteris paribus*, more international R&D if the country trades with other countries that export a high fraction of their output. This measure has the advantage of being less sensitive to

[12] The estimation results are robust to different depreciation rates, as shown by Coe and Helpman (1995) and Madsen (2007).

[13] The procedure of CH is not invariant to the level of data aggregation. A merger between two countries would always increase the stock of imports of technology. However, with the Lichtenberg and Van Pottelsberghe de la Potterie (1998) (LP) procedure the merge of two countries will not affect the stock of imports of technology.

yearly changes in the relative share of the exporter countries in the total volume of imports of country *i,* and hence it is less volatile.

Following the suggestions of Coe et al. (1997) and Xu and Wang (1999) the bilateral import weights are based on highly technological products, since technological spillovers through the channel of imports are more likely to take place through imports of technologically sophisticated products. To construct the two measures we have used 16 exporter countries: United States, France, Germany, United Kingdom, Japan, Italy, Spain, Switzerland, Sweden, the Netherlands, Norway, Denmark, Greece, Portugal, and Belgium[14].

Figure 2 compares the stock of patents by domestic inventors in the United States, Japan, France, Germany and the United Kingdom in a logarithmic scale. We can distinguish three patterns in the data. The U.S. shows a slightly upward trend until the beginning of the 1990's. Afterwards we can observe a sharp upswing that is related with a recent surge in the patenting activity in the U.S.[15]. The European countries show a different pattern of patenting with an essentially flat trend, as can be observed in the summary statistics of Table 1. In Germany and France the first years after the war were years of disruption in patent offices that provoked a reduction in the number of patents for the period 1945-1950[16]. This is reflected in a slightly downward trend in the stock during the first half of the 1950s. After the recovery of this fall, a slightly upward trend can be observed until the beginning of the 1970s, to observe a downward trend afterwards. By contrast, Japan has witnessed a steep upward trend in the whole period, reflecting its transition from a technological follower in the 1950s to a technological leader in the 1990s.

Figures 3 and 4 display the (logarithm of the) imports of knowledge for the two specifications we have calculated. In both estimates the evolution of the imports of knowledge depends on two factors: on the innovative effort made by the exporter

[14] Although we are aware that imports of highly technological products come mainly (around 50% or more) from the Big Seven countries (France, Germany, Japan, Italy, Sweden, United Kingdom and the U.S.), we have decided to use 16 countries for constructing our stock of imports of technology for two reasons. First, because in some cases imports coming from countries not belonging to this group are very high, as is the case of the U.S. where imports coming from Canada have the higher share. Second, because this is the procedure followed in other empirical researches (for example, CH, 1995; Keller, 1998; Xu and Wang, 1999; Lumenga-Neso et al., 2005; Madsen, 2007).

[15] Kortum and Lerner (1998, 1999) related this upsurge in patenting with changes in the management of research by the firms and not only to changes in US patent policy. In this case, the rise in patenting will not reflect a widening set of technological opportunities but a higher propensity of firms to protect their investment on R&D by means of patenting in advance.

[16] The German Patent Office in Berlin closed early in 1945 and was not reopened until 1950 in Munich (Federico, 1964).

countries (S_j^d) and on the evolution of trade of highly advanced goods. With regards to the first factor, the foreign stock of knowledge increases when the exporter countries increase their own stocks of patents and this is the same for the two measures of the stock of foreign patents. But it is the second factor which makes the difference between the two measures of the foreign stock of knowledge. In the case of CH weights, the imports of knowledge grow when the share of imports coming from the most innovative countries increases. And in the case of L&P weights, the import of knowledge grows when the propensity to export of the most innovative countries increases (L&P).

In Figure 3 we present the measure of the imports of knowledge using the CH specification calculated according to equation (4). In all cases we observe a slightly flat trend, except for the United States. We find that this fact reflects the aggregating procedure. The CH imports of knowledge add domestic stocks of patents weighted by the share of country *j* in the imports of technology of country *i*. Hence, the evolution of this variable depends both on changes in the domestic stocks of the exporter countries and on changes in the relative presence of the exporter countries.

There are two facts that could explain the flat trend of the CH foreign stock. First, domestic stocks of knowledge in the European countries showed a flat trend, or even a decrease, since the 1970s, as it has been shown in Figure 2. And additionally, the weight of the different countries in total imports of technology changed during the second half of the century, especially for the European countries. The presence of machinery imports coming from the United States (the country with the highest and increasing stock of domestic patents) decreased in favour of imports coming from their European partners (with lower rates of growth of the stock of domestic patents).

As can be observed in Table 2, imports of machinery and equipment coming from the U.S. range from 31.6% in 1953 to 13.4% in 2000 for France; from 30.4% to 16.3% in the U.K.; from 15.3% to 13.1% in Germany and from 69.5% to 27.9% for the case of Japan. Additionally, it is interesting to underline an increasing presence of Japan in the European imports that did not compensate the reduction of the United States presence. In the case of the United States the negative effect of the fall in European stocks of domestic patents is balanced by the greater presence of Japanese imports because this country shows a clear upward trend in its stock of domestic patents.

Figure 2. Domestic stock of patents

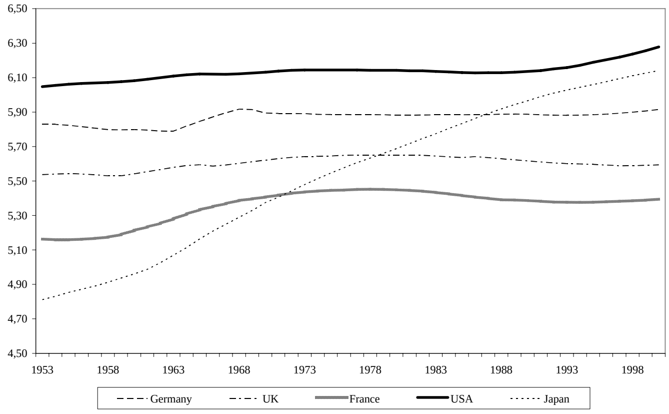


Figure 3. Imports of knowledge (CH)

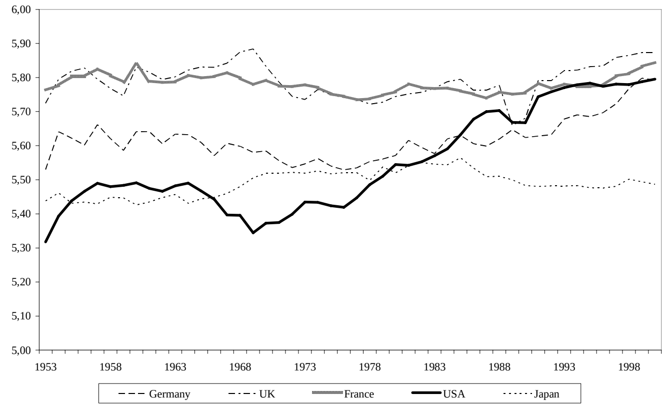
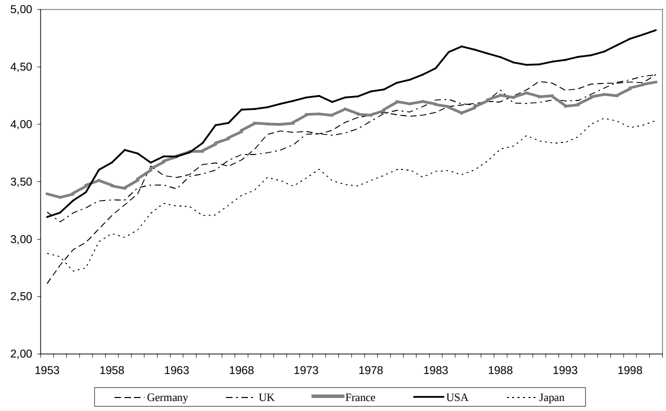


Figure 4. Imports of knowledge (LP)



Note: Imports of knowledge in Figure 3 are calculated according to the Coe and Helpman weighting scheme (see equation 4) and imports of knowledge in Figure 4 are calculated according to Lichtenberghe and Van Pottelsberghe de la Potterie method (see equation 5).

Table 2
Machinery and equipment imports by country of origin (% Share in total imports)

Importer Country	Exporter country	1953	1960	1973	1985	1995	2000
France	USA	31.69	33.54	15.00	16.38	12.33	13.46
	Germany	21.94	29.08	38.09	28.28	24.92	21.20
	UK	19.15	11.74	7.48	6.53	8.06	8.60
	Japan	0.00	0.01	2.68	7.59	7.17	7.25
Germany	USA	15.35	23.84	13.28	13.71	10.72	13.16
	UK	14.14	12.02	7.07	9.35	9.12	8.60
	France	8.44	14.17	20.34	16.66	13.58	11.43
	Japan	0.04	0.36	6.15	14.18	11.47	9.06
Japan	USA	69.56	61.28	53.99	61.60	35.55	27.91
	Germany	9.71	13.89	16.30	11.48	9.95	6.62
	UK	9.66	8.64	7.04	2.99	3.67	2.42
	France	1.97	1.94	2.76	1.41	1.81	1.35
UK	USA	30.46	35.67	18.59	20.03	15.95	16.31
	Germany	15.97	20.57	21.25	25.01	21.58	16.98
	France	6.39	7.59	11.75	8.49	9.87	8.31
	Japan	0.02	0.29	8.40	11.33	11.07	8.23
USA	UK	27.05	24.41	6.76	3.73	3.30	3.19
	Germany	12.19	29.12	17.59	9.73	6.38	6.66
	Japan	2.78	9.98	25.23	38.59	27.97	20.36
	France	2.19	5.99	2.15	2.71	2.25	2.55

Source: Conference Board and Groningen Growth and Development Centre. Total economy Data base, January 2009 at http://www.conference-board/economics/

Figure 4 displays the (logarithm of the) imports of knowledge following the weighting scheme proposed by LP (equation 5). The figure shows that the imports of knowledge have increased rapidly during the last forty years for all the countries in our study. The main reason for this evolution is the increase in the trade of highly technological goods, especially during the Golden Age, which increased the first multiplying term of equation 5. In this figure two different periods can be identified, especially for the European countries: an upward trend during the Golden Age period and a flat trend since the middle of the seventies, when the fall of innovation in the European countries adds to the reduction in the rate of growth of machinery and equipment trade (Table 3).

In figure 5 we plot jointly, for each country, the *TFP* growth rates, the domestic stock of patents and the two measures of the imports of knowledge. We find important differences across countries. In general, the imports of knowledge, measured using the LP weights, seems to have a stronger positive relationship with *TFP* growth than the

Table 3. Growth rate of machinery and equipment imports (Annual cumulative rates, %)

	1953-1973	1973-1985	1985-1995	1995-2005
France	14.35	-0.48	12.14	4.64
Germany	21.62	2.37	14.37	4.40
Japan	11.65	0.72	19.66	7.38
UK	13.46	1.65	9.93	6.95
USA	20.56	8.93	7.32	9.36

Source: United Nations *Yearbook of International Trade Statistics* for the years 1953-1962 and from Feenstra *et al*. (2005) for the years 1962-1985.

Note: Imports expressed in current US dollars have been deflated for all the countries by the US durable goods deflator from the BEA.

Figure 5. ***TFP* Growth and patent stocks growth rates**

CH indicator. The relationship between the LP imports of knowledge and *TFP* growth looks clearer for the European countries than for Japan, meanwhile in Japan the influence of the domestic stock of patents seems to be stronger than in the European countries. In the U.S. the LP imports of knowledge, that is made up of Japanese and European patents, seems to have had a positive influence on TFP growth, notwithstanding during the last decade the domestic stock of patents seems to dominate the evolution of productivity growth. All these correlations will be tested in the next section.

4. Econometric modelling and empirical results

To estimate the specified model of technology diffusion (equation 1) we have used cointegration time series techniques. The cointegration techniques allow capturing the notion of long-run equilibrium relationships that nonstationary variables may possess and, thus, have a tendency to move together in the long-run. This methodology is appropriate in this context as it permits avoiding any spurious regression while retaining the long-run information.

We estimate the long-run relationship between total factor productivity (*TFP*) growth and series of variables that measure technology achievement throughout the domestic and the imports of knowledge and a human capital variable.

To apply this methodology we first need to test for unit roots in order to determine the order of integration of the series; secondly, we study the possible presence of structural changes in the series; and, finally, we estimate the cointegration relationship between the variables using the appropriate order of integration of the series.

4.1. Stationary analysis

As a first step of the analysis, we test for the order of integration of the series. To this end, we use a modified version of the Dickey-Fuller and Phillips-Perron tests proposed by Ng and Perron (2001) that solve the main problems of these conventional tests for the unit roots.

In general, most of the conventional unit root tests suffer from three problems. First, they have low power when the root of the autoregressive polynomial is close to, but less than unity (De Jong *et al.,* 1992). Second, most of the tests suffer from severe size distortions when the moving-average polynomial of the first differences series has a large negative autoregressive root (Schwert, 1989). Third, implementing the unit root tests often implies the selection of an autoregressive truncation lag, *k*, which is strongly associated with size distortions and/or the extent of power loss (Ng and Perron, 1995). Trying to address these critiques, Ng and Perron (2001) have proposed a methodology that is robust to the three problems quoted above. This methodology consists of a class of modified tests[17].

In our results we obtain that the null hypothesis of non-stationarity for all series in levels cannot be rejected, independently of the test, whereas the existence of two unit roots cannot be rejected for the domestic stock of patent series (p_t^d) for France, Japan and the United States. Therefore, according to the results of these tests, the domestic stock of patents could be I(2) or I(1) for these three countries. [18]

However, a potential difficulty in assessing the time series properties of the economic variables is that they can be subject to potential structural breaks in the form of infrequent changes in the mean or the drift of the series, due to exogenous shocks or changes in the policy regime. Hence, in order to provide further evidence on the degree of integration of the domestic stock of patents, we have also applied the Perron-Rodriguez test (Perron and Rodriguez, 2003) for a unit root in the presence of a one-time change in the trend function. [19] The results for these tests indicate that the null hypothesis of non-stationarity for two of the series in levels (for Japan and the United States) cannot be rejected in any of the tests applied. Consequently, we can conclude that this variable is I(1) with one break in the trend function for Japan and the United States. We do not get the same conclusion for the domestic stock of patents series in France. [20]

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[17] These modified tests are namely $\overline{M}Z_{\alpha}^{GLS}$, $\overline{M}SB^{GLS}$ and $\overline{M}Z_{t}^{GLS}$, and were originally developed in Stock (1999) as *M* tests, with GLS detrending of the data as proposed in Elliot *et al.* (1996). In addition, Ng and Perron (2001) have proposed a similar procedure that corrects for the problems associated with the standard Augmented Dickey-Fuller test, ADF^{GLS}. In all cases, a Modified Akaike Information Criteria (*MAIC*) is used to select the autoregressive truncation lag, *k*, as proposed in Perron and Ng (1996). See Ng and Perron (2001) and Perron and Ng (1996) for a detailed description of these tests and the *MAIC* information criteria.

[18] The results of the tests are available from the authors upon request.

[19] Perron and Rodriguez (2003) extend the tests for a unit root analyzed by Perron and Ng (2001) to the case where a change in the trend function is allowed to occur at an unknown time, T_B.

[20] To apply these tests we select the break maximizing the absolute value of the *t*-statistic on the coeffeciente of the slope change. As before, these results are also available from the authors.

4.2. Long-run relationship

Once the order of integration of the series has been analyzed, we will estimate the long-run or cointegration relationship for each country separately. Given the (relatively small) time dimension of the series in our sample, we will estimate and test the coefficients of the cointegration equation by means of the Dynamic Ordinary Least Squares (DOLS) method put forward by Stock and Watson (1993), following the methodology proposed by Shin (1994). This estimation method provides a robust correction for the possible presence of endogeneity in the explanatory variables, as well as, serial correlation in the error terms of the OLS estimation. Also, to overcome the problem of the low power of the classical cointegration tests in the presence of persistent roots in the residuals of the cointegration regression, Shin (1994) suggests a new test where the null hypothesis is that of cointegration. We estimate a long-run dynamic equation including the leads and lags of all the explanatory variables, the so-called DOLS regression. In our case this relation is the following:

$$y_t = \alpha_0 + \alpha_1 t + \beta_k x_t + \sum_{j=-q}^{q} \gamma_j \Delta x_{t-j} + \varepsilon_t \qquad (6)$$

where y_t is *TFP* growth, t is a linear trend and x_t are the explanatory variables: a measure of the domestic stock of knowledge (measured through domestic patents), a measure of the imports of knowledge (measured through foreign patents using an import weighting scheme) and a measure of human capital, as explained in the previous section. The parameter β_k is the long-run cointegrating coefficient estimated between TFP growth and the explanatory variable k (or long-run elasticity).

In the above empirical model we will test for the type of cointegration (either stochastic or deterministic) using the Shin (1994) tests. The Shin tests we evaluate are based on the calculation of a LM statistic from the DOLS residuals, namely C_μ and C_τ, to test for deterministic (when $\alpha_1 = 0$) and stochastic (when $\alpha_1 \neq 0$) cointegration, respectively. If there is cointegration in the demeaned specification given in (6), that occurs when $\alpha_1 = 0$, this corresponds to deterministic cointegration, which implies that the same cointegrating vector eliminates deterministic trends as well as stochastic trends. But if the linear stationary combinations of I(1) variables have nonzero linear trends (that occurs when $\alpha_1 \neq 0$) as given in (6), this corresponds to stochastic cointegration.[21]

The coefficients from the DOLS regression and the results of the Shin test are reported in Tables 3 and 4. The results have been obtained using different measures of foreign stock of knowledge. In table 3 we report the results of the two models in which the foreign stock of knowledge has been calculated following the Coe and Helpman (1995) methodology (Model I and II). In table 4 we report the results for the two models in which the stock of knowledge has been calculated using Lichtenbergen and van Pottelsberghe de la Potterie (1998) weighting scheme (models III and IV). In both tables the term m_{it}, labelled as "Import interaction term, m_{it}" in the tables, indicates whether the log of the foreign knowledge stock has been multiplied by the propensity to import of the country.

The concept of deterministic cointegration is stronger than the concept of stochastic cointegration, therefore we sequentially test first for the presence of stochastic cointegration and then test for the presence of deterministic cointegration. In the first test, the null of stochastic cointegration is not rejected at the 1% level of significance for the five countries analysed.[22]

Next, we check for the presence of deterministic cointegration using the demeaned specification. For this second test, the null of deterministic cointegration is not rejected at the 1% level in all cases for France, Germany, United Kingdom and United States. However, for Japan the null of deterministic cointegration is rejected at the 1% level of significance for all cases. Thus, for the case of Japan, we only report the results for the deterministic cointegration.[23] In what follows we will discuss the results for the presence of deterministic cointegration for each country separately.

For France, we obtain that the imports of knowledge have a positive and significant long run relationship with *TFP* growth in the LP model, as theoretically expected.[24] The size of the coefficients estimated (i.e., the long run elasticities) for this variable is 0.09 (0.25) when we interact (do not interact) the foreign stock of knowledge with the import term. This means that a 1% increase in the imports of knowledge will

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[21] See Ogaki and Park (1997) and Campbell and Perron (1991) for an extensive treatment of deterministic and stochastic cointegration.
[22] The results of the tests for France, Germany, United Kingdom and United States are available from the authors upon request.
[23] The estimation results for the deterministic cointegration for Japan are available from the authors upon request.
[24] However, in the CH models this coefficient is not statistically significant.

Table 4
Total Factor Productivity as an endogenous variable

Country	Import Interaction Term m_{it}	Foreign Stock of Knowledge $P_t^{f,CH}$	Domestic Stock of Knowledge $P_t^{f,LP}$	Human Capital H	Cointegration Test statistics C_μ	C_τ
Model I: Foreign Stock of Knowledge (CH weighting procedure)						
France	NO	-0.13 (-1.45)	0.46 (10.41)	2.14 (35.1)	0.106	-
Germany	NO	0.28 (9.03)	0.40 (8.76)	1.26 (37.0)	0.075	-
Japan	-	-	-	-	-	-
United Kingdom	NO	0.07 (0.75)	0.22 (2.52)	0.66 (3.78)	0.086	-
United States	NO	-0.11 (-3.77)	0.85 (5.49)	4.44 (19.6)	0.068	-
Model II: Foreign Stock of Knowledge (CH weighting procedure)						
France	YES	0.02 (0.61)	0.53 (19.2)	1.90 (7.73)	0.074	-
Germany	YES	0.08 (6.49)	0.36 (3.70)	0.90 (13.7)	0.070	-
Japan	YES	0.35 (6.81)	1.79 (20.1)	2.74 (6.17)	-	0.101**
United Kingdom	YES	0.20 (3.41)	-0.64 (-2.78)	0.05 (0.17)	0.078	-
United States	YES	-0.36 (-14.8)	0.73 (17.3)	11.28 (27.5)	0.095	-

Notes:
[a] *t*-statistics in brackets. Standard Errors are adjusted for long-run variance. The long-run variance of the cointegrating regression residual is estimated using the Barlett window which is approximately equal to INT($T^{1/2}$), as proposed in Newey and West (1987).
[b] We choose q = INT($T^{1/3}$), as proposed in Stock and Watson (1993).
[c] C_μ and C_τ are LM statistic for cointegration using the DOLS residuals from the deterministic and stochastic cointegration, respectively, as proposed in Shin (1994).
[d] The critical values are taken from Shin (1994), Table 1, for m = 3: a) C_μ, 0.121 for the 10%, 0.159 for the 5% and 0.271 for the 1% levels; b) C_τ, 0.069 for the 10%, 0.085 for the 5% and 0.126 for the 1% levels.

Table 5

Total Factor Productivity as an endogenous variable

Country	Import Interaction Term m_{it}	Foreign Stock of Knowledge $P_t^{f,CH}$	Domestic Stock of Knowledge $P_t^{f,LP}$	Human Capital, H	Cointegration Test statistics C_μ	C_τ
Model III: Foreign Stock of Knowledge (LP weighting procedure)						
France	NO	0.25 (6.39)	0.33 (10.01)	0.59 (2.50)	0.097	-
Germany	NO	0.06 (1.24)	0.43 (1.49)	0.64 (2.27)	0.065	-
Japan	NO	0.29 (19.5)	1.29 (27.8)	3.76 (14.9)	-	0.082
United Kingdom	NO	0.04 (0.49)	0.21 (0.67)	0.67 (1.49)	0.081	-
United States	NO	-0.18 (-4.49)	0.34 (3.15)	8.32 (14.0)	0.078	-
Model IV: Foreign Stock of Knowledge (LP weighting procedure)						
France	YES	0.09 (3.96)	0.47 (19.21)	0.93 (3.20)	0.082	-
Germany	YES	0.06 (1.24)	0.43 (1.56)	0.64 (2.27)	0.065	-
Japan	YES	0.18 (23.7)	1.71 (50.59)	3.46 (18.1)	-	0.106**
United Kingdom	YES	0.15 (3.27)	-1.48 (3.58)	0.19 (0.45)	0.073	-
United States	YES	-0.08 (-5.69)	0.69 (7.61)	7.79 (19.8)	0.088	-

Notes:

[a] *t*-statistics in brackets. Standard Errors are adjusted for long-run variance. The long-run variance of the cointegrating regression residual is estimated using the Barlett window which is approximately equal to INT($T^{1/2}$), as proposed in Newey and West (1987).

[b] We choose q = INT($T^{1/3}$), as proposed in Stock and Watson (1993).

[c] C_μ and C_τ are LM statistic for cointegration using the DOLS residuals from the deterministic and stochastic cointegration, respectively, as proposed in Shin (1994).

[d] The critical values are taken from Shin (1994), Table 1, for m = 3: a) C_μ, 0.121 for the 10%, 0.159 for the 5% and 0.271 for the 1% levels; b) C_τ, 0.069 for the 10%, 0.085 for the 5% and 0.126 for the 1% levels.

increase the *TFP* in a 0.09% (0.25%). With respect to the domestic stock of knowledge we get in the two models presented, and regardless on whether we include an interaction term, a significant, positive and strong relationship between this variable and *TFP*. For the domestic stock of knowledge, the coefficients range from 0.33 to 0.53. Finally, the human capital variable is always significant, with the correct positive sign. From our estimates we get a long run elasticity that ranges from 1.90 to 2.40 in models I and II (with CH aggregation), and from 0.59 to 0.93 in models III and IV (with LP aggregation).

Our results are quite consistent with the historical interpretations of the economic performance for the French case. The explanations put forward have focused on the role of the *catching-up* theory, the new personnel at the front of the state and the opening to international trade (Sicsic and Wyplosz, 1996). The most important effect related to the international opening was to redirect trade away from the colonies and towards Europe. This provoked an increase in competition and, further, made French firms to become more competitive and increased firms' investment in innovation. As it can be observed in Figure 5, for France the domestic capacity of innovation and human capital variables went hand by hand with the imports of knowledge and hence with *TFP* growth. This could suggest that France made an important effort in terms of developing an endogenous capacity of innovation that was accompanied during the Golden Age by a big effort in education. Sicsic and Wyplosz (1996), in a descriptive analysis of the overall transformation of the French economy during the second half of the XXth century outlined the importance of the change in the institutions, specially the role of opening after the creation of the European Community, and the importance of investment in human capital.

We now turn to discuss the results obtained for the case of Germany. Our results, in relation to the imports of knowledge are positive and statistically significant for the specification in which we use CH weighting procedure[25]. The long run elasticity estimated ranges from 0.08 to 0.28, whether we consider or not the import term, respectively. With regards to the domestic stock of knowledge, the coefficients are higher and significant for the model in which we use the CH methodology, and range from 0.36 to 0.40.[26] The estimated long run elasticity is very high, as a 1% increase in the imports of technology would increase the *TFP* by 0.36-0.40%. Finally, the human capital variable is always significant and has a high positive impact on *TFP* growth, regardless of the model considered. The elasticity of human capital ranges from 0.64 to 1.26 when the propensity to import is not included and from 0.7 to 0.9 when it is taken into account.

[25] For Germany, we get insignificant coefficients for the foreign stock of knowledge in the model that uses LP methodology.

[26] As before, we do not get significant coefficients for this variable in the model that uses LP methodology.

However, it is interesting to stress that in Germany the effect of the domestic stock of knowledge is much larger than the estimates obtained for the imports of knowledge. Germany became a technological leader in some new industries with the turn of the ninetieth century, taking even advantage to the US in terms of productivity (for example, in chemical and pharmaceutical products)[27]. Even some authors argue that the high growth rates of Germany after the WWII might be more associated with the high reconstructing effort and less to the catching-up with the US (Janossy, 1969; Eichengreen and Rischtl, 2009), and specially to the new institutional arrangements created after the war that promote investment in physical capital and in intangibles, human capital and research and development (Carlin, 1996).

The third country we study is Japan. For this country the cointegration test only allow us to estimate the model with stochastic cointegration. Furthermore, we are not able to estimate the model for the CH specification when we do not include the interaction term. For Japan, we obtain that the three variables included in our specifications are positive and statistically significant. The higher positive elasticity corresponds to human capital, followed by the domestic stock of knowledge and, finally, by the imports of knowledge. The long run elasticity of human capital is very high, 3.76, when the import term is not considered, and it is 3.46 when we include the interaction term. As regards to the domestic stock of knowledge, the size of the elasticity is 1.29 in the first case and 1.71 in the second case. Finally, the technology developed abroad and introduced in the country by means of trade is significant and its elasticity ranges from 0.29 to 0.18. These elasticities are sensibly lower than those coming from the variables that represent the domestic effort in innovation and gave support to the idea that the Japanese rapid economic ascension after the WWII for Japan might mainly be attributed to a well-organized public and private domestic innovative activities (Freeman, 1987).

Now we turn to the case of the United Kingdom. For this country we get that the imports of knowledge are not significant for the specifications in which we have entered the interaction term. However, we get significant and positive long run elasticities for the specifications with this interaction, although the size of the long run elasticity is not very high (it ranges from 0.15 to 0.20). As regards the domestic stock of knowledge, we find the results for the U.K. very disappointing as in two of the cases, up to three, in which the coefficients are significant they are negative. In relation to human capital we do not get significant estimates, except for one of the specifications we use.

[27] Broadberry (1998) and Fremdling, De Jong and Timmer (2007).

The above results seem to be plausible due to the poor performance, in terms of productivity and output growth, of this country during the whole period. The U.K. is the unique country in our sample that did not experience a catch-up process during the Golden Age. Many explanations have been offered to understand the distinct behaviour for the U.K. Some of them are related with the proximate sources of growth, as were the low levels of investment in physical and human capital and the relatively weak total factor productivity growth. Other explanations emphasize the impact of institutional factors on investment as were the sclerotic industrial relationships or the short-termism of the macroeconomic policy management, that were devised more to control inflation and unemployment rates than to give impulse to the *TFP* (see Bean and Crafts, 1996).

Finally, we have also analysed the special case of the United States. As regards to the domestic stock of knowledge we get, as one would expect, a positive and significant long run relationship between domestic stock of knowledge and TFP growth. Meanwhile, the results with for the imports of knowledge are counterintuitive, significant and with an incorrect sign. Finally, human capital seems to be the more robust variable in the case of the U.S., with an elasticity that is higher than in the other countries. It ranges from 4.44 to 11.28 in the case of CH foreign stock, and from 7.79 and 8.32 in the case of LP foreign stock. These results are in line with the literature on the interpretation of the American economic leadership during the Twentieth century that stress the superiority with regard to Europe in the management of private and public investment in research and innovation (Nelson and Wright, 1992; Abramovitz and David, 1995) and the important gap in educational attainment (Goldin, 2001).

In summary, we find that the estimated elasticity for the domestic stock of knowledge had been higher than the elasticity for the knowledge coming from abroad. This result is consistent with the literature, where there is a wide consensus in considering that the effect of domestic R&D on productivity is stronger than that from foreign R&D in large countries, while in smaller ones the effect is the other way round.

Further, the estimated coefficients for the imports of knowledge interacted with the propensity to import, m, are significant at any conventional significance level and the variables are cointegrated. This result implies that the degree of openness favours international technology spillovers and consequently the more open an economy is, the higher the benefits a country can obtain from the technology developed abroad.

Our analysis sheds new light with respect to the asymmetries in the effects of knowledge spillovers through trade on *TFP* growth, a result also found by Acharya and Keller (2007). We get that the foreign stock of knowledge is only significant in the cases of the follower countries with a relative catching-up success (such as France, Germany and Japan), but it is not the case for the leading country (the U.S.) and for the U.K., where we cannot see a catching-up process.[28]

Finally, it is important to highlight that the domestic attainment in innovation could not be explained without taking into account the great effort in investment in human capital made by a country. The results obtained in this study, with regards to the role of human capital, confirm the recent developments in the theory of innovation-driven growth. We find strong evidence in favour of the complementarity between innovative efforts and human capital investment in the explanation of *TFP* growth. The human capital effort made possible to achieve a sufficiently qualified labour force, capable of operating with new and more advanced technologies, confirming human capital as a leading force in the explanation of *TFP* growth.

4. Conclusions

The catch-up hypothesis has occupied a prominent position for the explanation of economic growth during the second half of the XX[th] century. Its realization explains growth during the Golden Age and its exhaustion the subsequent slowdown after the oil shock. Additionally, more comprehensive explanations tend to give a superior role to the development of "social capabilities" in Europe, and also in Japan, that provided an endogenous stimulus to innovation during the Golden Age, to diminish their weight after the seventies. These capabilities have been considered a stimulus for investment in the context of a new international order more open to competition and trade. Domestically, the new commitment between the State, the entrepreneurs and the labour force created an environment where the risk for investment in new technologies seemed to be over control. Workers declined to claim higher wages, firms engaged in investing in new technologies and in creating new jobs and governments were committed to invest in the welfare state, in infrastructures, in innovation and in the formation of human capital.

In this paper we have put the Coe-Helpman (1995) hypothesis to test, by using an extended version of their model including human capital (see Engelbrecht, 1997). In particular, we propose a model of technology diffusion by considering the role played by both foreign and domestic stocks of knowledge and human capital on *TFP*. We have

[28] It is interesting to note that the estimated elasticities for the foreign stock of knowledge, when significant, are close to the elasticities achieved in the literature that uses R&D data. This suggests that the results are not sensitive to whether patent or R&D stocks are used.

carried out our analysis using a group of countries that belong to the selected group (the U.S., the U.K., France, Germany and Japan) of the most developed and innovative economies in the world (the Big Seven), using country data from the Groningen Growth and Development Centre, from O'Mahony (1996) database, from Morrisson and Murtin (2008) database and from the World Intellectual Property Organization Statistics database. To estimate the specified model of technology diffusion we have used cointegration time series techniques. We have estimated the long-run relationship between *TFP* growth and technology attainment though the domestic and imports of knowledge and human capital. This methodology allows avoiding any spurious regression while retaining the long-run information. To apply this procedure we have first tested for unit roots to determine the order of integration of the series. Secondly, we have checked the existence of structural changes in the series. Finally, we have estimated the cointegration relationship between the variables using the appropriate order of integration of the series.

Our results point out that both the domestic and the imports of knowledge play a significant role in explaining *TFP* growth. However, our results assign a less significant effect to the imports of knowledge from abroad meanwhile the domestic efforts in innovation seem to have a prominent effect on productivity growth. Further, we also find that investing in human capital is, by far, the most important factor determining *TFP* growth. These results reinforce the view that the role of domestic social capabilities is the most distinctive fact in explaining growth in the most developed countries. With regards to international technology spillovers we find them relevant only in those countries with a clear process of convergence with the U.S. (France, Germany and Japan) and non significant in the leader country and in the U.K., where a non-convergent trend dominates the period. Additionally, we can asses, in line with the existing literature, that the degree of openness favours international technology spillovers.

Finally, we can draw from our results an interesting conclusion for the most developed countries. The arrival of international flows of ideas is by no means sufficient to attain and maintain *TFP* growth; countries need a high level of domestic investment in knowledge and in human capital to maintain a sustained *TFP* growth. The impact of knowledge generated abroad is relatively weak compared with the high effect of the investment in human capital and with the overwhelming significance of domestic innovation. And, the relevance of this argument is higher the more developed a country is, as put forward when we compare the U.S. results with those of the remaining countries.

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