

**INTERNATIONAL TECHNOLOGY DIFFUSION THROUGH PATENTS**  
**DURING THE SECOND HALF OF THE XXTH CENTURY<sup>\*</sup>**

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**Abstract**

This paper analyzes the impact of domestic and foreign technology in explaining Total Factor Productivity (*TFP*) during the second half of the 20<sup>th</sup> century in some European countries (France, Germany, the U.K. and Spain). 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 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*; second, the elasticity of *TFP* to domestic innovation is higher than the elasticity to the imports of knowledge for the most advanced countries (France, Germany and U.K.), meanwhile domestic innovation remains not significant in the case of Spain, the less developed country of the group; third, in terms of contribution to *TFP* growth, the contribution of foreign innovation is always higher than the contribution of domestic innovation. Fourth, in the Golden Age period foreign technology spillovers were the main source in the explanation of *TFP* growth, losing its relevance in the subsequent period. And, finally, our results point that human capital plays a superior role in explaining *TFP* growth in the most advanced countries.

*JEL classification:* N14, O33, O47, O22

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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 XX<sup>th</sup> century<sup>1</sup>. 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 that provided an endogenous stimulus to innovation during the Golden Age but that loosed weight after the seventies. One relevant question to the understanding of the catch-up hypothesis refers to how technological progress entered into European countries, and to measure the contribution of technological *spillovers*, throughout trade in capital and intermediate goods, to *TFP* growth and convergence.

Developments in economic growth theory during the last two decades present a suitable framework for the study of these relationships. Endogenous growth models emphasize 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).

Coe and Helpman(1995) (CH, hereafter) were the pioneers in presenting empirical evidence in favour of the role of international technology diffusion throughout

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<sup>1</sup> Abramovitz (1986, 1989).

trade based on the endogenous theories of economic growth. Their 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 there is a vast literature that presents consistent results over several variables relationships. The first one 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. Although CH concluded that R&D produced *into* the trading partners spread to other countries by means of bilateral trade, it was early questioned by Keller (1998) who concluded that the direction of trade does not matter or at least it has 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. Lumenga-Neso *et al.* (2005) distinguish between “direct” spillovers (R&D generated into the exporter country) and “indirect” trade-related spillovers (foreign R&D experienced by the exporter country) and find that both are positive and significant in explaining *TFP* growth. More recently, Madsen (2007) obtains a similar conclusion using a different dataset (based on patents statistics over 135 years). Another conclusion of this literature refers to the relative role of the domestic technology effort and international technology spillovers. In the larger countries the elasticity of *TFP* to domestic R&D is higher than that relative to foreign R&D, whereas in the smaller countries occurs the reverse.

The literature based on international R&D spillovers has progressively incorporated new variables to the original CH specification. Engelbrecht (1997) introduced human capital to account for innovation outside the R&D sector and other aspects of innovation not captured by formal R&D. Since then, several studies have incorporated improved measures of this variable and, most of them, confirm a net significant and positive impact of human capital on productivity growth<sup>2</sup>. More recently, Coe, Helpman and Hoffmaister (2009) test also the impact of institutional factors that are now viewed as important determinants of economic growth. They find that countries with higher quality of tertiary education systems and where it is easier to do business tend to benefit more from their own R&D efforts, from international R&D spillovers and from human capital formation, than the countries where institutions are weaker.

The above empirical works restrict their analysis to a panel dataset of several OECD countries using as explanatory variables the stock of foreign and domestic knowledge generated from R&D expenditures. In line with the above literature, in this work we analyse the evolution of the *TFP* in four European countries during the second half of the XX<sup>th</sup> century and how it depends upon the domestic innovative efforts, on the foreign technology spillovers and on the accumulation of human capital. For that purpose we estimate the technology diffusion model introduced by Coe and Helpman (1995) and extended by Engelbrecht (1997) for four European countries 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 the Golden Age period, when the western countries reached the highest rates of output and productivity growth and reduced most of their

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<sup>2</sup> For example, see Frantzen (2000) and Barrio-Castro *et al.* (2002), among others.

technological gap with the U.S. 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 of innovation and technology diffusion<sup>3</sup>. Relative to R&D stock, patents data have the advantage of being available 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* in the European countries, but elasticities with regard to this variable are different depending upon the level of development and the degree of openness. Third, and more important, although in general the elasticity of *TFP* to domestic innovation is superior to that of imports of knowledge, the contribution of foreign innovation to domestic productivity is bigger than the contribution of domestic innovation, due to the superior amount of foreign innovation in comparison with the domestic one. Finally, international technology spillovers emerge as the main source of *TFP* growth in the Golden Age period, losing weight in the period after the oil shock.

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<sup>3</sup> 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.

The rest of the paper is organized as follows. In the second section, we review the historical background for explaining growth during 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<sup>4</sup>. Table 1 shows that while the U.S. 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 6.5 to 3 percent for Spain. The UK represents an exception due to the lower growth rates experienced during the whole Golden Age period. The same pattern can be observed in GDP *per capita* and *TFP* growth rates.

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<sup>4</sup> Different authors has been investigated this issue using diverse methodologies, trying to find a relationship between time and the growth rate (Crafts and Mills, 1996; Fagerberg and Verspagen, 2002). A more recent classification considers three sub-periods because of the high 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.**

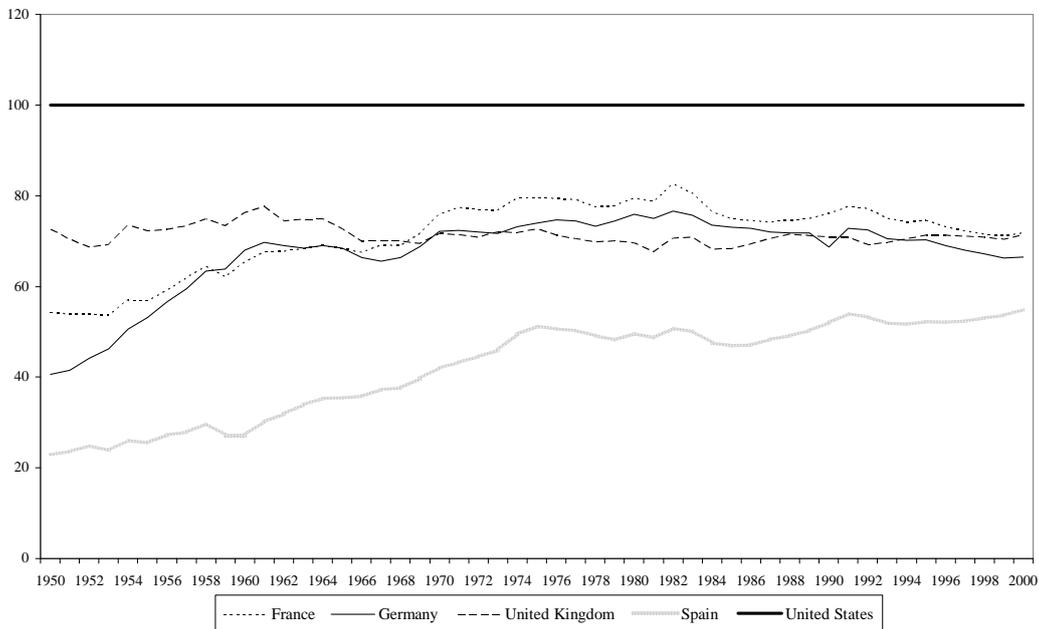
	France	Germany	United Kingdom	Spain	United States
<b>GDP</b>					
1950-1973	5.05	6.02	2.94	6.5	3.96
1974-2000	2.26	2.00	2.17	3.0	3.10
<b>GDP per capita</b>					
1953-1973	4.05	5.03	2.43	5.5	2.48
1974-2000	1.75	1.81	1.95	2.6	2.01
<b><i>TFP</i></b>					
1953-1973	4.47	3.02	1.60	4.4	3.88
1974-2000	1.14	0.80	1.66	2.3	3.57

Notes:

1. Source: GDP and GDP per capita calculations based on the Conference Board and Groningen Growth and Development Centre. Total economy database, January 2009 at <http://www.conference-board/economics/>.
2. For *TFP* calculations see section 3.

These growth rates allow identifying different periods of convergence and divergence, with respect to the U.S. income level. In Figure 1, we plot country convergence, defined by country *GDP per capita* expressed as a percentage of the U.S. *GDP per capita*. This indicator represents, relatively well, the idea of catching-up as a result of technology diffusion. In Figure 1 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 the growth trend started to slow down. Although all countries grew rapidly by their own historical standards, some seized the opportunities of the Golden Age better than others. For example, Figure 1 suggests that Germany, France and Spain performed relatively better than the U.K. in terms of *GDP per capita* convergence and in terms of *TFP* growth. 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 XX<sup>th</sup> century.

**Figure 1. Convergence trends with the U.S.**  
(GPD *pc* as a percentage of the U.S. 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 leading country, the U.S. In contrast, the period after 1973 appears as one of stagnation in output and productivity growth and as a period of no convergence with the U.S. The Golden Age period has been explained in different ways. Most of the explanations emphasize that the new economic conditions created a special environment for demand stability that boosted investment and fostered economic growth after the World War II<sup>5</sup>. The greater easiness for technology transfer, relative to the period before the WW II, was behind the reduction of the technological gap with the U.S. Further, this fact is a consequence of the dramatic reduction of trade barriers in the

<sup>5</sup> See Boltho (1982), Lamfalussy(1963) and Thirwall(1979), among others.

post-war world, especially between the industrialized countries, as evidenced by the dramatic rise in intra-European trade during the 1950s and the 1960s<sup>6</sup>.

In this period a set of innovations, jointly characterized as “mass production”, diffused through the economies of the developed world. These technologies were pioneer in the U.S. during the first half of the 20<sup>th</sup> 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. Although some European countries had 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 these technologies were particularly tailored to the resource endowments and market dimensions of the U.S. The decline in the transport costs and trade barriers after the WW II contributed to a rapid growth of domestic and international markets in Europe allowed the development of economies of scale and capital intensive technologies also within Europe and eased the access to cheaper natural resources.

The new impetus that trade gave to international transfers of technology was possible because of the development of new “social capabilities”. Eichengreen (1996, 2007) argues that the high investment rates which allowed successful exploitation of catch-up opportunities were facilitated by social contracts which sustained wage moderation by workers in return for high investment by firms. Economic agents 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. The international setting made the pact appealing by guaranteeing a minimum standard of living during the early post-war

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<sup>6</sup> 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.

years. It created an environment characterized by stability, both in domestic prices and exchange rates (Boltho, 1982), and by a growing international trade (Helliwell, 1992; Ben-David, 1993). Additionally, the state provided new conditions that favoured the agreement between workers and firms in the form of an expanded welfare state. These characteristics made agents confident about the real value of their incomes as well as about their future increases and made them more prone to investment and innovation.

### 3. Empirical Framework.

Coe and Helpman (1995) empirical specification provides a suitable framework for testing the importance of international transfers of technology for the explanation of productivity and convergence in the most advanced countries in the Golden Age period. In this paper we use the extended Coe and Helpman (1995) specification in order to explore the relative role of the international technology diffusion, measured throughout the stock of foreign patents and diffused throughout trade, the role of domestic innovation and human capital in the explanation of the long-run evolution of *TFP* in some European countries throughout the second half of the XX<sup>th</sup> century. In our empirical analysis we use the model proposed by CH and extended by Engelbrecht (1997) by adding a human capital variable. This model can be represented as follows:

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

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,  $m_{it}$  is the propensity to import (measured as the fraction of imports to GDP),  $H_{it}$  is the domestic stock of human

capital and  $\varepsilon_{it}$  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.

**a. Measurement of Total Factor Productivity.**

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

$$TFP_{it} = \frac{Y_{it}}{K_{it}^{\beta_{it}} \cdot L_{it}^{(1-\beta_{it})}} \quad (2)$$

where  $Y_{it}$  is real  $GDP$ ,  $K_{it}$  is capital stock,  $L_{it}$  is employment and  $\beta$  is the share of capital in total income. To calculate  $TFP_{it}$  we take the value of  $\beta$  from the *Groningen Growth Development Centre (GGDC) Database*.  $GDP$  is calculated at 1985  $PPP$  and expressed in millions of 1985 international U.S. dollars<sup>7</sup>. The original series for  $GDP$  come from the *GGDC* database<sup>8</sup> 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).

The (homogenous) series of capital stock are taken from O'Mahony (1996) for United Kingdom, France and Germany, since 1950. The capital stock is computed as machinery and equipment capital stock plus non-residential buildings and structures

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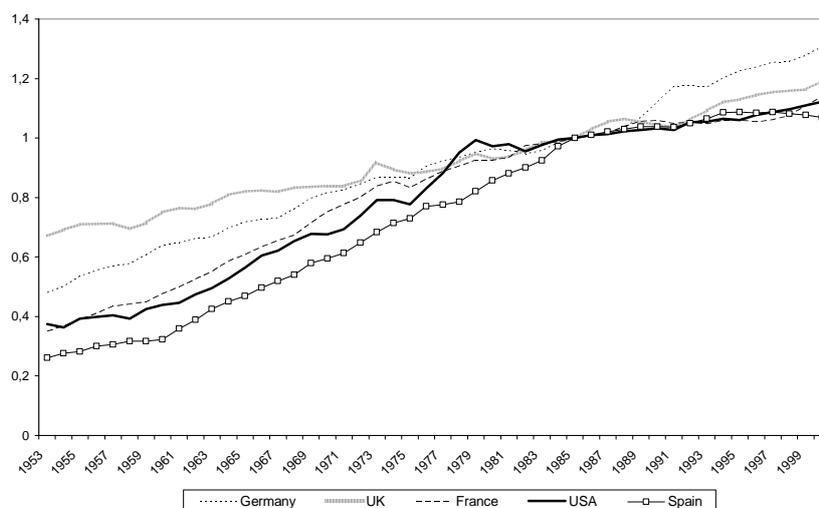
<sup>7</sup> The choice of 1985 as the benchmark year aims to be consistent with O'Mahony (1996) international comparable series of capital stock. This constitutes the unique database that offers homogeneous series of capital stock since 1950.

<sup>8</sup> See the web page <http://www.conference-board.org/economics> for details on the data provided.

capital stock. For Spain we have taken the capital stock series elaborated by Prados de la Escosura and Roses (2010).

Total employment is taken from the *GGDC* database. In this database 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 the U.S. and Germany. For the remaining countries (United Kingdom, France and Spain) this database offers data for the year 1950 and since 1955 onwards. With the aim to cover the years 1951 to 1954 we have assumed that employment grew at the same rate as population.

**Figure 2. Total Factor Productivity (1985=1).**



The *TFP* increased by an average of 200 percent since 1950 to 2000 and, as illustrated in Figure 2, we can distinguish two periods. The first covers from the beginning of the fifties until the mid seventies (1953-1975) and it is characterized by high growth rates of *TFP* in all the countries, in comparison with the second period (1975-2000). Notwithstanding, it is possible to observe important differences between

Spain, where the growth of *TFP* over the first period was much higher, increasing by a factor of 2.8, and the U.K in the other extreme, where *TFP* increased only by a factor of 1.31 over the same 22 years. In the second period, which started with the first oil shock, we observe a clear slowdown in productivity growth in all of the countries, with an average increase of 1.51 in Germany, 1.35 in the U.K., 1.36 in France, 1.44 in the U.S. and 1.46 in Spain.

### **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 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. Patents are widely accepted as a reliable indicator for the innovative activity when there is no appropriate data on R&D<sup>9</sup>.

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<sup>9</sup> See among others, 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). However, when using patent statistics as an indicator of inventive activity, the following issues should be taken into consideration, as put forward by Dernis, Guellec and van Pottelsberghe de la Potterie (2001) and Griliches (1990). 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 in 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.

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. In this 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 available since 1965 and only for the OECD countries. However, using patent data we can extend the time span of our research until the beginning of the 1950s, and hence we could incorporate the Golden Age period to our analysis.

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

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

where  $S_{it}^d$  is the patent stock for country  $i$  in year  $t$ ,  $p_{it}$  is the number of new patents in country  $i$  in year  $t$  and  $\delta$  is the depreciation or obsolescence rate, which was assumed to be 5 percent<sup>10</sup>. 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 ( $S_{it}^{f,CH}$ ):

$$S_{it}^{f,CH} = \sum_j \frac{m_{ijt}}{m_{it}} S_{jt}^d \quad (4)$$

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<sup>10</sup> The estimation results are robust to different depreciation rates, as shown by Coe and Helpman (1995) and Madsen (2007).

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) (LP, hereafter) criticize this method of aggregation due to its sensitivity to the level of data aggregation that makes it highly volatile<sup>11</sup>. Their alternative measure is:

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

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 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 15 exporter countries: United States, France, Germany, United Kingdom, Japan, Italy,

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<sup>11</sup> 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) procedure if two countries merge, the stock of imports of technology will not be affected.

Spain, Switzerland, Sweden, the Netherlands, Norway, Denmark, Greece, Portugal, and Belgium<sup>12</sup>.

Figure 3 compares the stock of patents by domestic inventors in the United States, France, Germany, the United Kingdom and Spain in a logarithmic scale. As it can be observed, the increase in the domestic stock of patents was much smoother, as compared with the rise in *TFP*. Further, 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.<sup>13</sup> The European countries show a different pattern of patenting with an essentially flat trend. 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<sup>14</sup>. This is reflected in a slightly downward trend in the stock during the first half of the 1950s., followed by an upward trend until the beginning of the 1970s and a clear downward trend afterwards. A striking fact observed in Figure 3 is the poor goals reached by Spain in terms of domestic innovation. Spain was, at the beginning of the period, at a long distance with regards to the other countries, and it did not make any progress in its relative position.

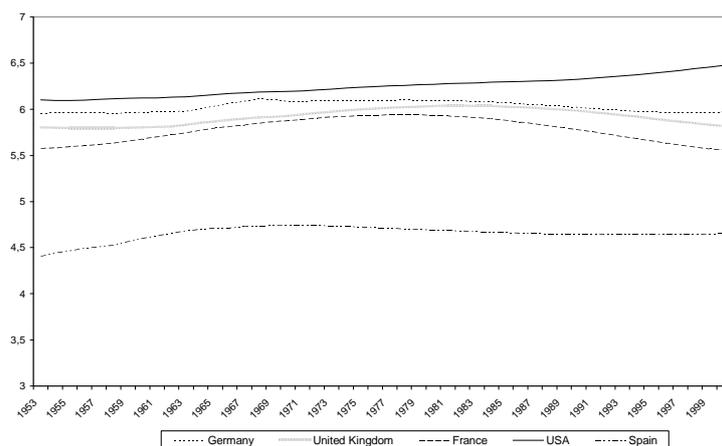
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<sup>12</sup> Although we are aware that imports of highly technological products come mainly (around 50% or more) from the Big Seven countries (France, Germany, Japan, Italy, Sweden, United Kingdom and the U.S.), we have decided to use 16 countries 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, such 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).

<sup>13</sup> 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 U.S. 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.

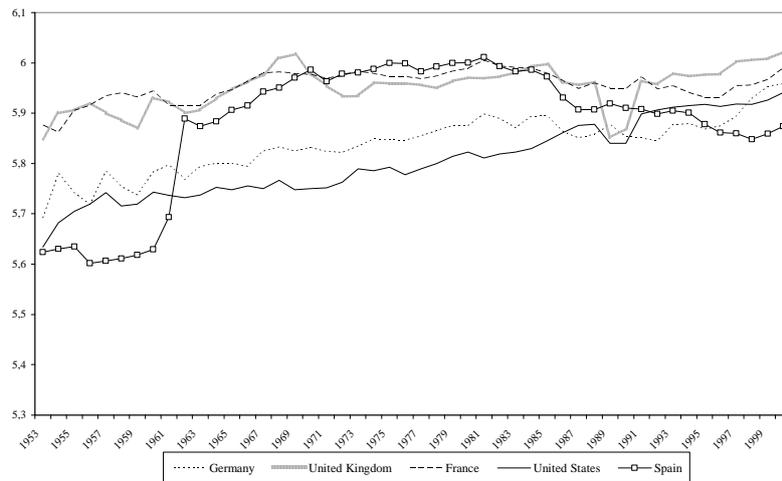
<sup>14</sup> The German Patent Office in Berlin closed early in 1945 and was not reopened until 1950 in Munich (Federico, 1964).

**Figure 3. Domestic stock of patents.**



Figures 4 and 5 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 countries ( $S_j^d$ ) and on the evolution of trade of highly advanced goods. It is the second factor that 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 imports coming from the most innovative countries increase their share in total imports, and, in the case of LP weights, the imports of knowledge grow when the propensity to export of the most innovative countries increases, this is to say, when an increasing proportion of the output produced in the exporter country comes into the importer country. By this way, the LP aggregation better reflects how an increase in the volume of trade will increase international technology spillovers.

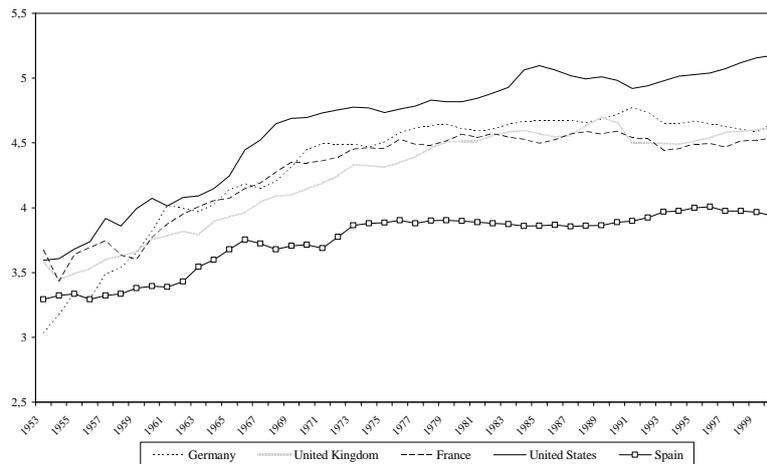
**Figure 4. Imports of Knowledge (CH).**



Notes:

1. Imports of knowledge are calculated according to CH weighting scheme (see equation 4).
2. Source: See the main text.

**Figure 5. Imports of Knowledge (LP).**



Notes:

1. Imports of knowledge are calculated according to LP weighting scheme (see equation 5).
2. Source: See the main text.

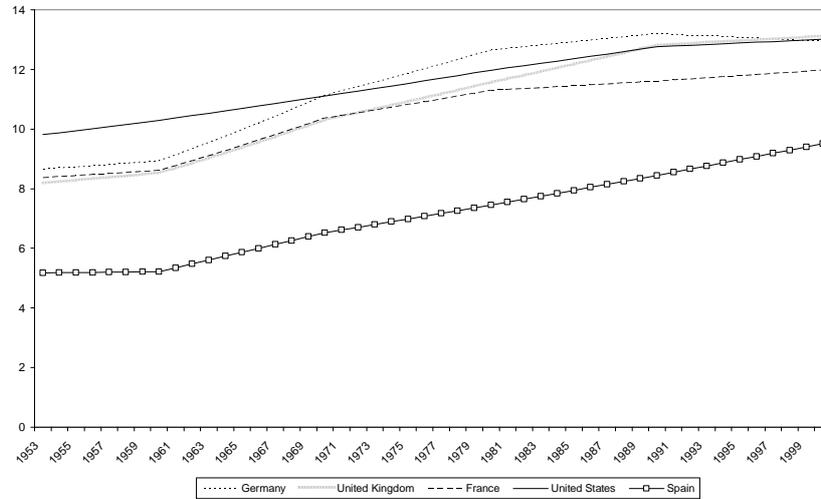
In Figure 4 we present the measure of the imports of knowledge using the CH specification calculated according to equation 4. In all cases we observe a slightly flat trend, except for the United States. There are two facts that could explain the flat trend of the CH foreign stock. First, domestic stocks 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 second, the direction of trade of technological advanced products changed throughout the period in favour of products coming from other European countries and against imports coming from the U.S. This fact is not neutral in terms of the capacity of generating technological spillovers because the United States appears as the most innovative country for the whole period.

Figure 5 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. 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, the propensity to export of country  $j$  to country  $i$ . As in the case of the *TFP*, 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.

Finally in our study we have included a human capital variable. The human capital data are taken from Morrison 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 (2008) have constructed original series from census information and for the period 1960-2010 they have taken Cohen and Soto (2007) database. As the Morrison and Murtin (2008) 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.

**Figure 6. Human capital.**



Source: See the text.

Human capital increased in all countries from 1953 to 2000. The largest increase was in Spain, where the average years of schooling almost doubled from 1961 to 2000. Spain made this effort in order to converge with the most developed countries in terms of education, although it could not close this gap because the increase in the human capital was also to large in the other countries, specially between 1961 and 1990.

#### **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 innovation 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<sup>15</sup>.

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<sup>15</sup> These modified tests are namely  $\overline{MZ}_\alpha^{GLS}$ ,  $\overline{MSB}^{GLS}$  and  $\overline{MZ}_t^{GLS}$ , 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

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 ( $S_t^d$ ) for France. Therefore, according to the results of these tests, the domestic stock of patents could be I(2) or I(1).<sup>16</sup>

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.<sup>17</sup> The results for these tests indicate that the null hypothesis of non-stationarity for France is not always rejected. Consequently, we can not conclude that the domestic stock of patents series in France is I(1) with one break.<sup>18</sup>

## 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

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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.

<sup>16</sup> The results of the tests are available from the authors upon request.

<sup>17</sup> 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,  $T_B$ .

<sup>18</sup> To apply these tests we select the break maximizing the absolute value of the  $t$ -statistic on the coefficient of the slope change. As before, these results are also available from the authors.

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:

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

where  $y_t$  is the log of *TFP*,  $t$  is a linear trend and  $x_t$  are the explanatory variables: the log of the domestic stock of knowledge (measured through domestic patents), the log 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  $\beta_k$  is the long-run cointegrating coefficient estimated between *TFP* 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. These tests are based on the calculation of a LM statistic from the DOLS residuals, namely  $C_\mu$  and  $C_\tau$ , 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  $\alpha_I \neq 0$ ) as given in (6), this corresponds to stochastic cointegration.<sup>19</sup>

The coefficients from the DOLS regression and the results of the Shin test are reported in Tables 2 and 3. The results have been obtained using different measures of foreign stock of knowledge. In table 2 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 3 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 3 and 4). 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 country propensity to import.

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 four countries analysed.<sup>20</sup> 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 Spain.

We start the discussion of the results analysing the results for France. For this country we obtain that the imports of knowledge have a positive and significant long

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<sup>19</sup> See Ogaki and Park (1997) and Campbell and Perron (1991) for an extensive treatment of deterministic and stochastic cointegration.

<sup>20</sup> The results of the tests for France, Germany, United Kingdom and United States are available from the authors upon request.

run relationship with *TFP* in the LP model, as theoretically expected.<sup>21</sup> 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 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 3 and 4 (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* hypothesis, 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. In France the domestic capacity of innovation and human capital variables went hand by hand with the imports of knowledge and hence with the evolution of *TFP*. 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 XX<sup>th</sup>

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<sup>21</sup> However, in the CH models this coefficient is not statistically significant.

century outlined the importance of the change in the institutions, specially the role of opening after the creation of the European Community for stimulating investment, 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<sup>22</sup>. 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.<sup>23</sup> 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.

However, it is interesting to stress that in Germany the elasticity 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 U.S. in terms of productivity (for example, in chemical and pharmaceutical products)<sup>24</sup>. One of the most supported explanations of the West German economic miracle in the 1950's, when GDP grew by nearly 8 % per annum, is the reconstruction effort thesis. According to this argument the negative output shock in the final phases of the war and immediately after pushed off

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<sup>22</sup> For Germany, we get not significant coefficients for the foreign stock of knowledge in the model that uses LP methodology.

<sup>23</sup> As before, we do not get significant coefficients for this variable in the model that uses LP methodology.

<sup>24</sup> See for example Broadberry (1998) and Fremdling and De Jong and Timmer (2007).

the economy from its long term growth path. Hence, in the immediate aftermath of the war, there was a large gap between actual and potential output due to severe factor distortions (Jánosy, 1969). This fact made that the labour-capital ratio were initially very low, inducing exceptional rates of investment and growth. This hypothesis has been recently restated (Eichengreen and Ritschl, 2009) and even reinforced considering that the reconstruction extended its effects ever further than the mere reconstruction by stimulating capital renewal (Vonyó, 2008). Another interesting argument refers to the fact that Germany was also more successful than other economies, such as the United Kingdom, in terms of human capital accumulation (O'Mahony, 1999). These hypotheses are supported by our results (as can be seen in the next section), as for Germany, those variables related with the domestic effort in terms of human capital or accumulation of domestic knowledge the elasticities estimated are always positive, significant and higher to those attributable to foreign spillovers. Further, for Germany the domestic effort in investment and knowledge received a higher response in terms of productivity growth than in the remaining countries analyzed in this study. With regard to the positive effect of foreign transfers of technology we find also arguments in the literature that indicate that institutional changes in Germany drove to pro-market reforms under U.S. aegis that put the German economy on a path toward European and world market integration (Olson, 1982). These changes promoted investment in physical capital and in intangibles, human capital and research and development (Carlin, 1996).

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 not entered the interaction term. However, we get significant and positive long run elasticities for the specifications with this interaction term, although the size of the long

run elasticity is not very high (it ranges from 0.15 to 0.20). With regard to 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. The human capital variable does not get any significant estimate (except in one of the specifications).

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 *TFP* 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 *TFP* (see Bean and Crafts, 1996). Further explanations emphasize the weaker competition in the U.K. because the slower liberalization of external trade in comparison with Germany (Crafts and Mills, 1996) and the lack of incentives to competition at the firm level due to agency problems (Nickell *et al.*, 1997). All of these factors prevented the effective assimilation of American technology and are consistent with our results relative to both the poor elasticities with regard to domestic innovation and to foreign imports of technology.

Finally, we have also analyzed the special case of Spain. We consider Spain a special case as it is a country that started the period with the lowest income levels of *GDP per capita* in the sample, but experienced a notable process of convergence with the most developed countries during the Golden Age. Our results reveal that the entry of

foreign technology throughout trade was a relevant variable in the long-run evolution of *TFP* of this less developed country. The long run elasticity estimated ranges from 0.92 to 0.22, whether we consider or not the import term following the CH aggregation; and from 0.46 to 0.27, with the LP aggregation. The positive and significant effect when we introduce the import interaction term, confirms that the inflow of technology throughout trade has been reinforced by the Spanish increasing openness to international trade, which is particularly interesting if one takes into account that Spain was nearly an autarchic country in the forties and part of the fifties. As regards to the domestic stock of knowledge, we get very disappointing results. The domestic stock of knowledge is not significant in any specification<sup>25</sup>. These results are in line with the traditional interpretation of the Spanish economic growth, which states that in a relatively backward economy, like Spain in the middle of XX<sup>th</sup> century, the incorporation of foreign technology was a straightforward way to introduce more up-to-date knowledge than devoting domestic scarce resources to make its own research. The same kind of result was obtained by Madsen *et al.* (2010) for the Indian case.

As in the other countries analyzed, human capital seems to be also a robust variable in the case of Spain, with an elasticity that runs from 0.78 to 1.5. This confirms that the notable effort made by Spain to improve its relatively low level of human capital and to converge with the average educational attainment level of the OECD countries, seems to have had a positive impact over the Spanish overall productivity.

Finally, it is interesting to compare the results obtained across countries. In the case of the most advanced countries of the sample (France, Germany) we find that the estimated elasticity for the domestic stock of knowledge had been higher than the

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<sup>25</sup> The lack of significance of the stock of patents is possibly attributable to the weakness of the series of patents because when other measures of domestic innovation are used, such as the domestic stock of R&D, this variable is significant, with the correct positive sign but with an elasticity lower than that of the imports of knowledge (Cubel, Esteve, Sanchis and Sanchis-Llopis, 2011).

elasticity estimated for the foreign knowledge, meanwhile just the opposite occurs for Spain, a less developed country, where the productivity is more sensitive to the imports of knowledge. In this sense, our analysis sheds new light with respect to the asymmetries in the effects of knowledge spillovers through trade on *TFP* growth for countries with different levels of development (Acharya and Keller, 2007). Additionally, 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 Spain), but it is not the case for the U.K., where we cannot see a clear catching-up process.<sup>26</sup>

Further, when the estimated coefficients for the imports of knowledge are interacted with the propensity to import, they 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. The relative stability of the coefficients of foreign knowledge gives further credibility to the CH hypothesis that the direction of trade, at least, in the post II World War period, has been important for the international diffusion of knowledge. Additionally, it is also noteworthy to highlight that the estimated elasticities both for the domestic and foreign stock of knowledge are close to the elasticities achieved in the literature using R&D data, as it is also found in Madsen (2007) who uses patent data.

Finally, the achievements in innovation, domestic or foreign, could not be reached without taking into account the great effort in investment in human capital made by the countries. The results obtained in this study, with regards to the role of human capital, confirm the recent developments in the theory of innovation-driven

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<sup>26</sup> 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.

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 allow to have 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.

**Table 2. Total Factor Productivity as an endogenous variable**

	Model 1: Foreign Stock of Knowledge ( $S_{it}^{f,CH}$ ) (without import interaction term)				Model 2: Foreign Stock of Knowledge ( $S_{it}^{f,CH}$ ) (with import interaction term)			
	France	Germany	United Kingdom	Spain	France	Germany	United Kingdom	Spain
$S_{it}^d$	0.46 (10.41)	0.40 (8.76)	0.22 (2.52)	-0.31 (-8.13)	0.53 (19.21)	0.36 (3.70)	-0.64 (-2.78)	-0.35 (-5.64)
$S_{it}^{f,CH}$	-0.13 (-1.45)	0.28 (9.03)	0.07 (0.75)	0.92 (5.17)				
$m_{it}S_{it}^{f,CH}$					0.02 (0.61)	0.08 (6.49)	0.20 (3.41)	0.22 (1.72)
$H_{it}$	2.14 (35.1)	1.26 (37.0)	0.66 (3.78)	1.50 (30.30)	1.90 (7.73)	0.90 (13.7)	0.05 (0.17)	1.19 (5.88)
$C_{\mu}$	0.106	0.075	0.086	0.067	0.074	0.070	0.078	0.087
$C_{\tau}$	-	-	-	-	-	-	-	-

Notes:

<sup>a</sup>  $t$ -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  $\text{INT}(T^{1/2})$ , as proposed in Newey and West (1987).

<sup>b</sup> We choose  $q = \text{INT}(T^{1/3})$ , as proposed in Stock and Watson (1993).

<sup>c</sup>  $C_{\mu}$  and  $C_{\tau}$  are LM statistic for cointegration using the DOLS residuals from the deterministic and stochastic cointegration, respectively, as proposed in Shin (1994).

<sup>d</sup> The critical values are taken from Shin (1994), Table 1, for  $m = 3$ : a)  $C_{\mu}$ , 0.121 for the 10%, 0.159 for the 5% and 0.271 for the 1% levels; b)  $C_{\tau}$ , 0.069 for the 10%, 0.085 for the 5% and 0.126 for the 1% levels.

**Table 3. Total Factor Productivity as an endogenous variable**

	Model 3: Foreign Stock of Knowledge ( $S_{it}^{f,LP}$ ) (without import interaction term)				Model 4: Foreign Stock of Knowledge ( $S_{it}^{f,LP}$ ) (with import interaction term)			
	France	Germany	United Kingdom	Spain	France	Germany	United Kingdom	Spain
$S_{it}^d$	0.33 (10.01)	0.43 (1.49)	0.21 (0.67)	-0.55 (-20.05)	0.47 (19.21)	0.43 (1.56)	-1.48 (3.58)	-0.44 (-15.20)
$S_{it}^{f,LP}$	0.25 (6.39)	0.06 (1.24)	0.04 (0.49)	0.46 (4.40)				
$m_{it}S_{it}^{f,LP}$					0.09 (3.96)	0.06 (1.24)	0.15 (3.27)	0.27 (3.19)
$H_{it}$	0.59 (2.50)	0.64 (2.27)	0.67 (1.49)	0.96 (7.75)	0.93 (3.20)	0.64 (2.27)	0.19 (0.45)	0.78 (3.38)
$C_{\mu}$	0.097	0.065	0.081		0.082	0.065	0.073	0.088
$C_{\tau}$				0.072				

Notes:

<sup>a</sup>  $t$ -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).

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

<sup>c</sup>  $C_{\mu}$  and  $C_{\tau}$  are LM statistic for cointegration using the DOLS residuals from the deterministic and stochastic cointegration, respectively, as proposed in Shin (1994).

<sup>d</sup> The critical values are taken from Shin (1994), Table 1, for  $m = 3$ : a)  $C_{\mu}$ , 0.121 for the 10%, 0.159 for the 5% and 0.271 for the 1% levels; b)  $C_{\tau}$ , 0.069 for the 10%, 0.085 for the 5% and 0.126 for the 1% levels.

## 5. The contribution of innovation to *TFP* growth and convergence.

In this section, we calculate the relative contribution of the three variables (domestic stock of patents, imports of knowledge and human capital) to the overall increase in *TFP* for the whole period. For this purpose, we use a 5 % depreciation rate for the domestic and the foreign stock of knowledge. To calculate the decomposition we use the estimated elasticities of Table 3 (without import interaction term, i.e., models 3 and 4) and we obtain the *TFP* growth decomposition illustrated in Table 4.

**Table 4. *TFP* growth decomposition (in %) by components.**

	<b>Domestic stock of patents, <math>S^d</math></b>	<b>Imports of knowledge, <math>S^f</math></b>	<b>Human capital, <math>H</math></b>	<b>Unexplained</b>
<b>Germany</b>	11.49	63.10	24.74	0.66
<b>United Kingdom</b>	10.20	20.80	50.78	18.21
<b>France</b>	9.87	56.30	26.10	7.73
<b>Spain</b>	-23.68	24.36	43.15	56.17

It is noteworthy that although the estimated elasticities for foreign knowledge are superior to the elasticities with regard to the domestic stock of knowledge, in all countries the contribution of the imports of knowledge to *TFP* growth exceeds the contribution of domestic innovation, and this is so because the increase in the stock of knowledge in the rest of the world is always superior to the advances in one particular country. In Germany and France where *TFP* growth was higher than in the case of the U.K., the contribution of the imports of knowledge is bigger than 50 %.<sup>27</sup> These results are in line with those obtained in the literature. For example, Madsen (2007) concludes

<sup>27</sup> This results are not comparable with those obtained for Spain where the poor explanatory power of domestic patents invalidate the results.

that the imports of knowledge are responsible, on average, for a 93% increase in *TFP* in a sample of 16 OECD countries for the period 1870-2004. From these results we can draw two conclusions. First, even in the case of the most advanced countries, imports of technology emerge as a key factor for the assimilation of new technology and for productivity growth. And second, and not less important, in this research we obtain higher elasticities for the domestic innovation for these particular countries, than those obtained in Madsen (2007) for a panel of OECD countries, suggesting that the evolution of *TFP* in the most developed countries is very sensitive to the generation of an endogenous capacity of innovation.

We have also calculated this decomposition by sub-periods (1953-1975 and 1975-2000) using the long run elasticities<sup>28</sup>. In general we observe that during the Golden Age period, 1953-1975, the contribution of foreign imports of knowledge to *TFP* was higher than in the subsequent period. In Germany, the contribution of the imports of knowledge to *TFP* growth decreased from 61.6 % in 1953-1973 to 4.81 % in 1976-2000; in the United Kingdom, it decreased from 16.8 % to 4.9 %; and, in France, it changed from 63.3 % to 22.2 percent.

Finally, we compare our results with those obtained by Eaton and Kortum (1999). These authors estimate a model of innovation that explores the relationships within and between countries, among technology, research, patenting and productivity. They found that, even in the most innovative countries (United Kingdom, United States, France, Germany and Japan), research performed abroad is about two-thirds as important as domestic research. In order to compare our results to those presented by Eaton and Kortum (1999) we split the total contribution of innovation (foreign plus domestic) to *TFP* in two parts, one corresponding to domestic innovation and the other

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<sup>28</sup> Due to shortness of the series, we have not been able to separately estimate elasticities by sub-periods, and hence we have used the same elasticities for the two periods analysed.

to foreign imports of knowledge (see Table 7). Our results confirm that in the case of Germany the contribution of foreign innovation to *TFP* growth was 84%, this percentage is 67.1 % for the United Kingdom and 85.1% for France. These results are similar to those illustrated by Eaton and Kortum (1999), where the fraction of productivity growth due to research performed abroad was 84 % in Germany, 89% in France and 87% in France<sup>29</sup>.

**Table 7. Domestic versus foreign innovation (in %)**

	<b>Domestic innovation, <math>S^d</math></b>	<b>Foreign innovation, <math>S^f</math></b>
<b>Germany</b>	14.4	84.6
<b>United Kingdom</b>	32.9	67.1
<b>France</b>	14.9	85.1

## **5. Concluding remarks.**

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*. Our main target is to review a popular explanation for the performance of the European countries in the Golden Age period, which highlights the role of international transfers of technology as a key determinant issue in the explanation of overall productivity growth and convergence in those years.

We have carried out our analysis using a group of European countries (the U.K., France, Germany and Spain) that experienced a clear process of catching-up with the

<sup>29</sup> See Eaton and Kortum (1999), table 5.

most developed country, the U.S., during the second half of the twentieth century, using country data from the Groningen Growth and Development Centre, from O'Mahony (1996) database, from Morrisson and Murin (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* and technology attainment through the domestic stock of knowledge, the imports of knowledge and a human capital variable. 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 domestic innovative efforts and the imports of knowledge play a significant role in explaining *TFP* growth. Our results assign a minor elasticity to *TFP* with regard to the imports of knowledge than to human capital or domestic innovation, specifically in those advanced countries with a relative success in terms of catching-up such as Germany or France. Meanwhile, we find the opposite results for Spain, the less developed country of the sample, where foreign innovation seems to be the driving force. However, when we analyse our results in terms of the contribution of each term to *TFP* growth, the results seem to change in favour of a dominant role of the international spillovers of technology in explaining productivity performance. This last result is even more evident for the Golden Age period, when the imports of technology were favoured both by a process of openness to international trade and a process of market integration between Europe and the U.S.

Finally, we can draw, from our results, the following conclusion for the most developed countries. The arrival of international flows of ideas is a key factor for productivity growth when there is scope for a technological gap to be closed; simultaneously and even thereafter, 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 was relatively weak after the Golden Age period, meanwhile other factors such as the investment in human capital and the development of domestic innovation seem to take over.

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