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International R&D spillovers in Central and Eastern Europe. The role of capital imports and local conditions

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Abstract

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Key words: Imports of capital goods; Productivity; CEE countries; Local conditions

JEL classification: C33; F14; O4

Introduction

In this paper we focus on productivity growth in the Central and Eastern European (CEE) member countries of the European Union (EU-10) and its relationship with international transactions.[1] These countries have a common past and similarities, but regarding their economic development, structure and endowments they form a heterogeneous region. Significant disparities exist in income and productivity levels. In 2013, per capita GDP in Slovenia, at 21,300 euros (in PPP-adjusted prices), was still almost twice that in Bulgaria, at 12 000, and in Romania, at 13 900.[2] There have also been significant discrepancies in their efforts to stimulate domestic innovation. Slovenia, Czech Republic and Estonia are the best performers in this sense, showing levels in per capita expenditure on R&D that are close to those of the EU countries. In contrast, in 2013, per capita expenditure on R&D in Romania and Bulgaria did not even reach 10% of the EU average.[3]

After their integration into the EU and before the economic crisis, productivity grew spectacularly in the new EU member states. The increase in competitiveness was the main stimulus to economic growth and the driving force behind their convergence toward the income and productivity levels of advanced industrial countries. However, this productivity growth, far from coming from domestic innovations, was mainly a consequence of foreign factors. As Meriküll et al. (2013) have shown, the innovation effort in CEE countries has been modest and differences in knowledge creation between CEE and EU are even greater than the differences in income. External sources of productivity such as trade and foreign investment have been crucial in their economic catching-up process by stimulating knowledge transfers and innovation (IBRD, 2008). Among these external factors, we concentrate on imports of capital goods as the main driver of international technology diffusion and productivity growth.

International technology diffusion through capital imports has been broadly studied in the economic literature.[4] The transfer of knowledge embodied in the trade of capital goods was already underlined by Rivera-Batiz and Romer (1991). Since then, there seems to be a consensus among researchers that less industrialized countries may benefit from technological innovations that occur in the more industrialized ones. According to Xu and Chiang (2005), for instance, productivity gains that stem from leader countries' R&D are spread around the world through trade and patenting. Similarly, Keller's model (2004) predicts that the import patterns of countries are relevant to their productivity behavior. Specifically, it shows how a country that imports primarily from a leader country receives more technology embodied in intermediate goods than another that imports from follower countries. Coe and Helpman (1995) and Coe et al. (1997) confirm this hypothesis showing empirically that countries which are more open to machinery and equipment imports from the world's technology leaders have also experienced faster growth.

However, productivity spillovers may be constrained by the limited ability of countries to adopt new technologies. In this sense, the level of a country's human capital has been considered both a source of productivity growth and one of the main factors determining the capacity of a country to learn and absorb new technologies (Benhabib and Spiegel, 1994; Coe et al., 1997; Seck, 2011). According to Benhabib and Spiegel (1994), for instance, human capital facilitates the adoption of technology from abroad and enhances the creation of domestic technology. In addition to human capital, other authors such as Cohen and Levinthal (1989), Borezstein et al. (1998), Griffith et al.

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[1] We include in our analysis those countries that joined the EU in 2004 and 2007 (EU-10). According to the World Bank (2008), the transition is over for these countries. We have not considered, however, the experience of Croatia as this economy joined the EU after the period we study here (1995-2009), more specifically, in July 2013.
[2] Source: Eurostat
[3] Eurostat data source.
[4] See Keller (2004) for a survey.

(2004), and Keller (2004) also emphasize the role played by domestic R&D in providing the necessary background for technology adoption. For Cohen and Levinthal (1989), firms' ability to assimilate technological knowledge from abroad can be dependent on their own innovation effort.

The degree of success in adopting foreign technology has been further related with the technological gap, and particularly with the distance between the level of domestic technology and the technology frontier (Nelson and Phelps, 1966). According to Crespo et al. (2002), the effect of the technology gap on international spillovers is not unambiguous, as it may act in two opposite directions. On the one hand, the greater the technological gap of a country is, the higher the potential gains from foreign technology spillovers are expected to be. On the other hand, a greater technological distance may imply a lower capacity to adopt foreign technology, and thus gains can be restricted. For Glass and Saggi (1998), a larger development gap entails a lower capability of domestic firms to benefit from potential spillovers from foreign presence.

This paper provides additional evidence on the linkages between the international transfer of technology and productivity in the CEE member states, using a new and harmonized industry-level data set. Following Coe and Helpman (1995) and Coe et al. (1997), we consider the stock of knowledge embodied in capital goods imports from advanced countries to be the main driver of technology diffusion. In this work, we place special attention on the role played by local conditions in the assimilation of foreign technology, and particularly on the level of human capital, domestic R&D, and the technological gap as determinants of absorptive capacity. We also consider the different patterns of technology adoption by development stages. To do this, we divide the sample into country groups according to the per capita GDP and R&D efforts.

Some previous empirical works have also investigated the links between foreign transactions and productivity in the CEE countries. However, most of them focus on the effect of FDI on productivity. This is, for instance, the case of Holland and Pain (1998), Barrel and Holland (2000), and Bijsterbosch and Kolasa (2010).[5] The few studies that do analyze the impact of capital imports on economic performance across countries employ aggregate data (Kutan and Yigit, 2009) or use firm-level data, but concentrate on one specific country (such as Halpern et al., 2009, for Hungary). As an exception we can mention the work by Meriküll et al. (2013). Using industry-level data, these authors investigate the effect of foreign R&D stock on the productivity level for six CEE countries between 1995 and 2007. In our paper, we analyze both theoretically and empirically the links between capital imports and productivity growth, taking into account the fact that the influence of foreign technology on the domestic economic performance may be related with local conditions and with the different levels of development. Our empirical analysis is based on industry-level data from all CEE member states (EU-10) during the period from 1995 to 2009, thus including the effects of the global economic crisis. For the sake of increased robustness, we use alternative estimation methodologies and specification models.

Our findings suggest the following conclusions. Firstly, capital imports from developed countries are a significant channel of technology diffusion and productivity growth in the CEE member states. These benefits are even more substantial in the less advanced economies than in the more advanced ones. Secondly, our estimates suggest that countries with a larger stock of physical and human capital, domestic R&D, and that are closer to the technology frontier enjoy more productivity gains. Finally, the outcomes reveal that a greater technology gap limits the productivity-enhancing effects associated with endowments of skills and the international transmission of technology.

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[5] For other references, see Javorcik (2008).

The structure of the article is as follows: in the first section, the evolution of productivity, domestic R&D, and human capital in the CEE region are described. In the second section, we present our theoretical model and its implications. The database and the econometric methodology are described in the next section. The fourth section presents the results of our estimations, and the final section concludes.

I. Productivity growth in the CEE countries

Before and after adhesion to the EU, the CEE region experienced considerable growth. Between 2000 and 2007 average EU real GDP growth was 2.3%, while for the ten CEE countries it reached 6.2%, the highest level being attained in the Baltic States.[6] A major factor behind this growth was the growth of productivity. Benkovskis et al. (2013) found that even between 1996 and 2007 productivity growth was generally higher in CEE countries than in Western Europe. However, they also found differences among CEE countries themselves.

Figure 1. Value Added per worker.
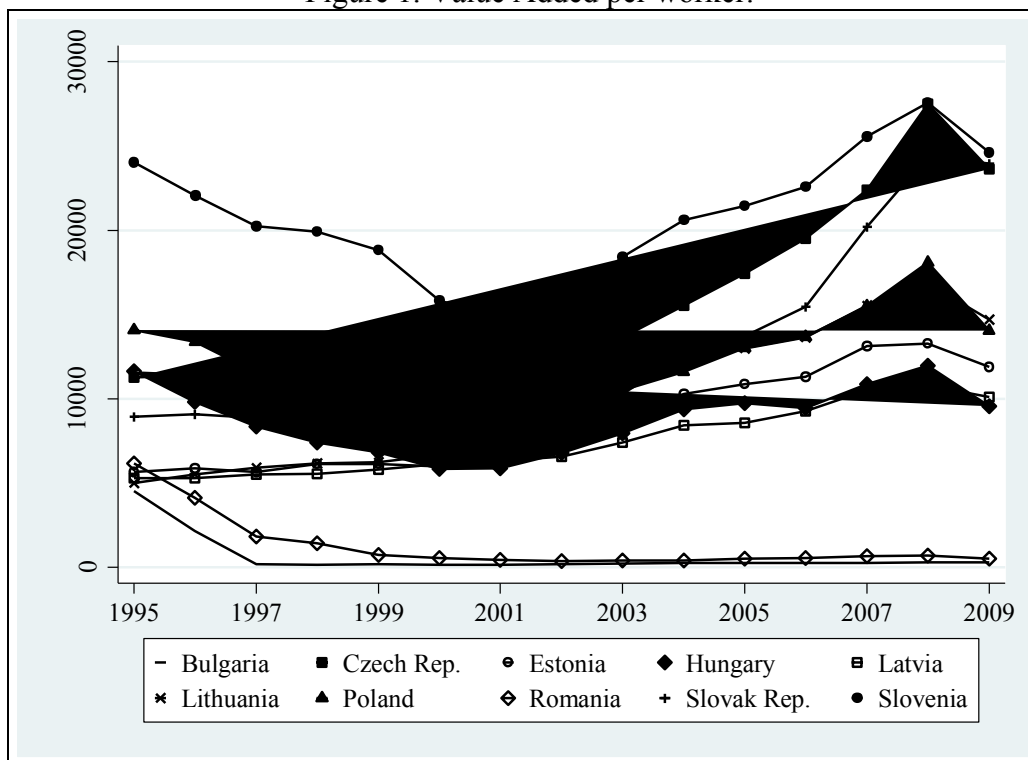
Source: Own elaboration based on WIOD data.

Figure 1 shows country-specific dynamics of labor productivity for the CEE group. At a first glance, two different patterns may be distinguished. On the one hand, Bulgaria and Romania show a downward slope over the period. On the other hand, the rest of the countries show a positive trend, and more specifically so after 2001/2002, where we can highlight the increasing evolution of Slovenia, Slovakia and the Czech Republic (after the significant drop up to 2001). The financial crisis of 2008 is also present in this figure through the breaking point in the evolution of labor productivity. These productivity paths may be influenced by several factors. In this paper, we focus on the international transmission of technology (research and development activity from foreign transactions) and domestic conditions (domestic R&D, human capital, and technology gap).

[6] Calculations from Eurostat data.

4

Technology development seems to be the main driver of productivity gains. In large and "capital-strong" developed countries, domestic R&D activity is especially significant whether financed by the state or by the enterprise sector. In the case of the CEE countries, however, the lack of domestic capital has been substituted by foreign capital since the nineties. The electronic, automotive and machinery branches are in general under foreign control. But, apart from manufacturing, foreign capital imports are also important in the service sector. In certain countries and sectors, foreign firms have been financing R&D activity to a large extent or almost entirely. Foreign multinational companies established affiliates and transferred knowledge and technology to CEE economies, thus enhancing productivity. However, in general, the measurement of these spillover effects is difficult; they can be country- or sector-specific and they may depend on the methodology or dataset used (Barrios et al., 2009). Moreover, officially registered data in CEE countries on FDI flows capture fewer and fewer real effects on the economy.[7] These facts prevent us from including foreign direct investment in our analysis, focusing on imports of capital goods as the main factor of technology diffusion and productivity growth.

Since the seminal paper by Rivera-Batiz and Romer (1991), the important role that imported capital goods play as a foreign source of technology diffusion and productivity growth has been highlighted in many theoretical and empirical works (see, for instance, Coe and Helpman, 1995; Coe et al., 1997; Keller, 2004; Acharya and Keller, 2009; Seck, 2012). According to these works, a country's productivity depends on its own R&D capital stock, but also on the R&D capital stocks of its trade partners. As new technology is embodied in capital and intermediate goods, the direct import of these goods is a channel of transmission (Keller, 2004; Acharya and Keller, 2009). Indeed there are also studies which claim the impact of foreign intermediate imports is more important for smaller countries than for larger ones (Barba Navaretti and Tarr, 2000; Keller, 2004). Similarly, Coe and Helpman (1995) find that foreign R&D may have a stronger effect on domestic productivity the more open an economy is to international trade. In general many authors suggest a positive relationship between openness to trade and technology adoption (Balasubramanyam et al., 1996; Cuadros et al., 2004). In most of the smaller countries the elasticity of factor productivity is larger with respect to the foreign R&D capital stock than with respect to the domestic one. In the case of CEE countries, imports are one of the most important foreign R&D transmission channels, as shown by Meriküll et al. (2013).

In this paper, we focus on capital goods imports as a channel of transmission of foreign R&D. More specifically, we compute imports from G7 countries of capital goods (particularly, machinery, NEC, electrical and optical equipment, and transport equipment). Additionally, we weight them by the R&D intensity of the exporter country (measured as R&D expenditure over value added). Figure 2 shows the evolution of these R&D imports for the ten CEE countries considered. Two different groups may be distinguished: those which increased their R&D imports during the period analyzed – Hungary, the Czech Republic and Slovakia – and those that did not.

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[7] In recent years there are unusually large FDI inflows and outflows in the same quarter of the year or in the short term in certain CEE countries. This phenomenon is defined as *capital in transit*. These are transactions within a multinational enterprise group that pass through the compiling economy without making an impact, do not finance development projects, but do distort the statistics on the components of foreign direct investment. Capital in transit is not easy to distinguish, as the affected companies are organically integrated into the economy.

Figure 2. R&D imports from G7 countries.
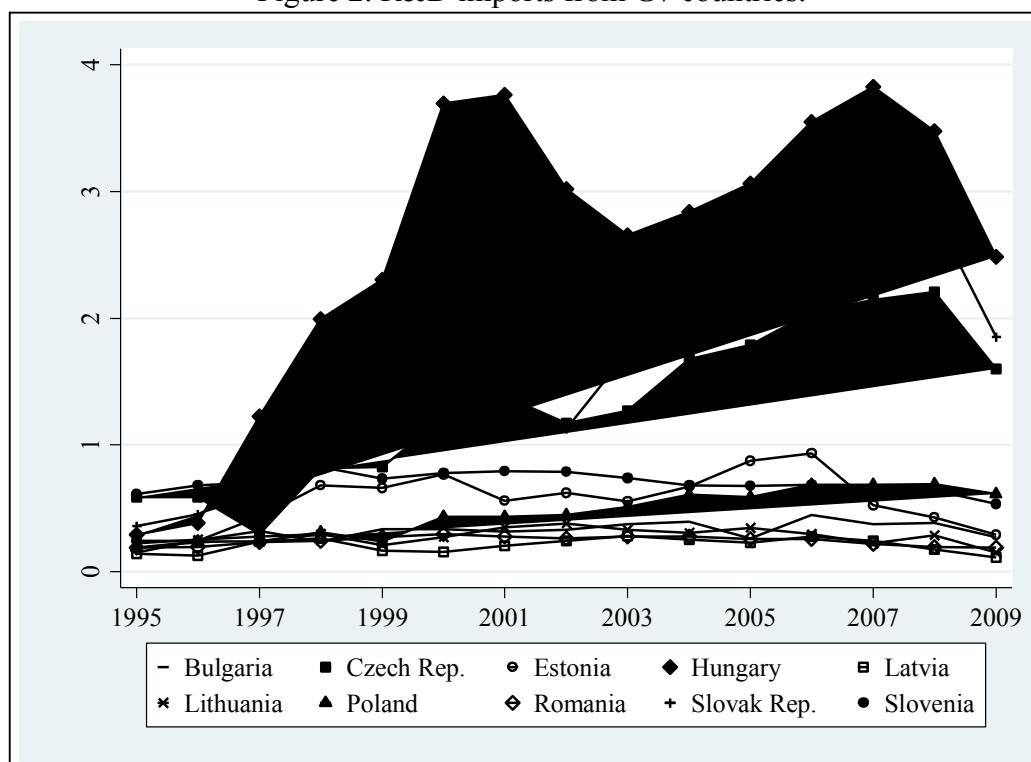
However, as mentioned above, the magnitude of the technology spillovers depends on the local capacity to successfully adopt foreign technology.[8] The assimilation of knowledge spillovers will be greater the higher the absorptive capacity of the host country is.[9] Two major determinants have been emphasized as the main local factor that facilitates technology adoption: domestic R&D and human capital (Benhabib and Spiegel, 1994; Borenzstein et al., 1998; Griffith et al., 2004; Keller, 2004; Henry et al., 2009). According to Griffith et al. (2004), domestic R&D and human capital are key factors for successfully adopting foreign technology when these are employed in "imitative" or "adaptive" research activities. Keller (2004) and Henry et al. (2009) also emphasize the role played by research and development expenditures and human capital in providing the necessary skills for technology adoption.

The extent of technology diffusion has also been associated with the distance to the technological frontier (see, for instance, Benhabib and Spiegel, 1994; Glass and Saggi, 1998, and Crespo et al., 2002). Specifically, Benhabib and Spiegel (1994) adapt Nelson and Phelps (1966)'s model to allow human capital levels to affect the speed of technology catch-up and diffusion. For Glass and Saggi (1998), the quality of technology transmission to less developed economies from more developed ones depends on the size of the technology gap. In recent years, this technological gap seems to have been reduced somewhat in the countries analyzed. There has been a growing convergence in the research and development efforts of CEE countries with respect to the EU average level (see Table 1 below). However, this convergence is heterogeneous in its pace and degree. Slovenia, Czech Republic and Estonia are the best performers, showing the highest increase and highest level in per capita R&D spending. By contrast, Romania, Poland and Bulgaria are those with the lowest spending on R&D (per person) of all CEE countries.

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[8] This was shown previously in Cuadros and Alguacil (2014), where 28 developing economies were analyzed in a period of a decade.
[9] Crespo and Fontoura (2007) provide a survey of absorptive literature.

Table 1. Ratio of total R&D expenditure (GERD) per capita, (EU28 = 100).

	2004	2005	2006	2007	2008	2009	2013
Bulgaria	3.2	3.4	3.6	4.0	4.6	5.2	6.8
Czech Republic	27.4	30.7	34.3	38.1	40.3	39.1	53.2
Estonia	15.3	18.7	25.7	28.1	32.4	31.3	46.1
Latvia	5.2	7.9	11.6	12.4	13.5	8.3	12.9
Lithuania	10.2	11.5	13.3	15.5	16.7	14.9	20.9
Hungary	18.1	20.3	20.5	21.1	22.0	22.5	26.6
Poland	7.6	8.9	9.1	10.1	12.0	11.6	16.8
Romania	2.8	3.7	4.8	6.7	8.2	5.8	5.2
Slovenia	48.2	50.6	55.4	54.1	64.0	68.4	84.7
Slovak Republic	8.2	8.9	9.2	10.2	11.8	11.9	21.1

Source: Own elaboration based on Eurostat data.

Research and development is mainly financed by the business sector, by the government, and from abroad. Regarding the CEE countries, the share of the business sector is similar to the EU average in Estonia, Hungary and Slovenia. But in general, all these countries have a much higher share (10%-50%) of finance from abroad than the EU average (9%).[10] Following the transition period, CEE countries show rising innovative activity either in own inventions or co-inventions. Regarding the number of patents (granted by the US patent office) relative to inhabitants until 2010, Hungary, the Czech Republic and Estonia have significantly higher results than the other CEE countries.[11] Concerning the number of patent applications filed (relative to inhabitants) Slovenia, Estonia, Hungary and the Czech Republic are the leaders.[12] However, patenting is costly and not so frequent in the CEE region as in Western Europe. Besides, as Veugelers (2010) puts it, for catching-up, emerging countries' patents are inadequate to measure innovation activity, because this indicator is biased in favor of countries at the technology frontier.

Concerning the human capital, the economic literature describes its endowment as a direct determinant of productivity, as well as one of the main factors of absorptive capacity. Based on Coe et al. (1997), many empirical works include human capital as a source of productivity growth (Seck, 2012). The quality of human capital depends on education, skills and creativity, and thus it is not easy to measure. According to EBRD (2013), primary school students in transition regions achieve slightly lower scores than those in advanced economies.[13] At the secondary level, however, Estonia shows outstanding qualities and other countries are also usually above the EU average. Things are rather different when we look at tertiary education, however. As highlighted by Kwiek (2014), universities had previously been underfunded in the transition countries and significant higher education reform started only after EU adhesion. The Bologna Declaration was signed by most countries in the region and its implementation began with a number of problems. In spite of these difficulties, higher education in the CEE countries has expanded over the past 20 years, although at different rates (as can be seen in Table A1 in the appendix).

The above picture on the state of R&D and human capital in CEE economies justifies the fact that we have included them as explanatory variables in our model. It is also obvious that there are considerable differences among the countries observed. These countries are also diverse in their level of economic development (usually measured by GDP per capita). Table 2 below shows that their differences in per capita GDP do not coincide with the geographic location of the countries.

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[10] Eurostat data for 2011.
[11] United States Patent and Trademark Office, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm
[12] World Economic Forum: Global Information Technology report. http://reports.weforum.org/global-information-technology-report-2013/.
[13] EBRD Transition Report 2013: "Quality of education and human capital".

Table 2. Nominal GDP, Purchasing Power Standard per capita, euros.

	2004	2005	2006	2007	2008	2009	2013
EU 28	21 600	22 400	23 600	25 000	25 000	23 500	25 700
Bulgaria	7 500	8 200	9 000	10 000	10 900	10 300	12 000
Czech Republic	16 900	17 800	18 900	20 600	20 200	19 400	20 600
Estonia	12 400	13 800	15 600	17 500	17 200	14 900	18 600
Latvia	10 100	11 100	12 500	14 300	14 600	12 700	17 300
Lithuania	11 100	12 300	13 600	15 500	16 100	13 600	19 100
Hungary	13 600	14 200	14 900	15 300	15 900	15 300	17 200
Poland	10 900	11 500	12 300	13 600	14 100	14 200	17 500
Romania	7 500	8 000	9 200	10 700	12 200	11 700	13 900
Slovenia	18 700	19 600	20 700	22 100	22 700	20 200	21 300
Slovak Republic	12 300	13 500	14 900	16 900	18 100	17 000	19 600

Source: Eurostat.

It can be seen that, although the Baltic countries share strong common ties in history and in geography, in terms of GDP per capita Estonia is more developed than the other two economies. Bulgaria and Romania are the least and Slovenia and the Czech Republic are the most developed countries. Using these facts and the already described characteristics of R&D and human capital – these being the most relevant to our study – we constructed two groups of countries in our sample. The relatively well-advanced CEE countries with comparatively more intensive R&D activity belong to one group: Slovenia, Czech Republic, Estonia, Slovakia, and Hungary (this latter is a borderline case, but because of its relatively high R&D expenditure we included it in the more advanced group). The other group is made up of the less advanced economies with less R&D effort: Bulgaria, Romania, Latvia, Lithuania, and Poland.

II. Theoretical considerations

As mentioned before, according to the literature, international trade is crucial for foreign technology diffusion. For Acharya and Keller (2009) and Keller (2004), for instance, technology is embodied in capital and intermediate goods, so the direct import of these goods is a channel of transmission. To illustrate this point, we present here a simple model of international technology diffusion. More particularly, we adapt Liu (2008)'s and Ehrlich et al. (2004)'s model by considering the transferred (adopted) technology as an intermediate good which increases the aggregate productivity of all its inputs, as well as the initial conditions in the host economies for both the creation of new technologies and the absorption of the spillovers associated with foreign transactions. Within an endogenous growth framework, Liu (2008) extends Ehrlich et al. (2004)'s model by incorporating technology spillovers into the production function at the firm level. This model suggests that the spillovers related to foreign capital lead to a decline in short-term productivity but an increase in the long-term rate of productivity growth of domestic firms.

In our model, the transfer of superior technologies through foreign transactions, and in particular through imports of capital goods, spreads across the entire economy leading to productivity gains in domestic firms. Similar to the standard knowledge production function, we include the stock of knowledge as a separate input in the Cobb-Douglas production function (T). Specifically, assuming that foreign countries have more advanced technology, we specify the home country production function as:

$$Y_{ijt} = A_{ij} L_{ijt}^{\alpha} K_{ijt}^{\beta} T_{ijt}^{\gamma}$$

where Y_{ijt} is total output, and K_{ijt} and L_{ijt} denote capital and labor, respectively. T_{ijt} represents the average technical knowledge stock of the home industry that is subject to continuous accumulation. A_{ij} is a technical factor. In this model, this factor is treated as exogenous in order to focus on the impact of the spillovers associated with foreign transactions. The subscripts i, j and t denote country, sector and time, respectively.

Here, the stock of knowledge serves as a specific input for the home production that augments labor productivity, as in Lucas (1988) and Romer (1990). However, in our model, technical progress associated with knowledge emerges from foreign transactions rather than from R&D activities or human capital.[14] If the technology associated with foreign transactions, in the form of managerial skills as well as new products and processes, are partially public, this may be used by other firms as an unpaid input factor, thereby increasing the growth rate of the technology input in the home economy.[15]

The accumulation of new technology, g_T, follows here the law of motion (similarly to that described in Lucas, 1988, for human capital). Particularly, the production of additional technological inputs requires a stock of knowledge that may come from two sources: (i) The technology stock of the home country, and (ii) the knowledge spillovers associated with foreign transactions. Thus, the accumulation of new technology will depend on both the current level of domestic technology, T, and the spillovers that occur through the technology transfer from the most advanced economies, F. That is:

$$g_{T_{ijt}} = r_{ijt} T_{ijt} F_{ijt}^{\varphi} \tag{1}$$

where $\varphi \geq 0$ is the intensity of spillovers and r_{ij} is an efficiency factor that represents the fraction of technological input employed in the adoption of new technology.[16] To attain any unit of knowledge, an industry j in country i needs $r_{ij} > 0$ new units of technical knowledge. Not all countries and their industries are equally efficient in adopting foreign technology. The extent to which the new technology obtained through foreign transactions is translated into domestic technological progress and productivity growth depends on the capacity of the sector and the country to maximize foreign spillovers (Bijsterbosch and Kolasa, 2010; Cuadros and Alguacil, 2014). Thus, the value of this parameter will rely on the technology absorption capacity, such as the level of domestic skills or the level of basic technology literacy.

From Eq. (1), and assuming constant returns to scale with respect to domestic capital and labor, we can write the labor productivity, LP_{ijt}, at home, in sector j at time t as:

$$LP_{ijt} = \frac{Y_{ijt}}{L_{ijt}} = A_i (K_{ijt} / L_{ijt})^{\beta} T_{ijt}^{\gamma}$$

Taking natural logs, the above equation can also be expressed as:

$$\ln LP_{it} = \ln A_{ij} + \beta \ln k_{ijt} + \gamma \ln T_{ijt}$$

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[14] In our model, domestic R&D activities and human capital facilitate the absorption of new technology, but they are not the driving force behind them. The CEE countries observed are not among the strong innovators in the world and their technology is less developed.

[15] As in Romer (1986), spillovers are non-appropriable by firms and affect the whole economy.

[16] This equation is inspired in the specification suggested by Benhabib and Spiegel (1994), which indicates that technical change depends on both innovation and imitation.

where lowercase letters denote per worker values. Then, taking first differences, we can express the growth rate of labor productivity (g_{LP}) as an increasing function of domestic capital per worker growth (g_k) and the accumulation of knowledge of the economy (g_T), as $\gamma > 0$.[17]

$$g_{LP_{ijt}} = \beta g_{k_{ijt}} + \gamma g_{T_{ijt}} \qquad (2)$$

In short, on combining Eq. (1) with Eq. (2), we can say that the growth rate of labor productivity is influenced by foreign transactions through the transfer of a superior technology. The greater the exposure of the home country to the international transactions and the greater the country's capability to adopt foreign technology domestically are, the higher this technology factor is assumed to be. Both domestic conditions (the absorptive capacities and the average knowledge stock) and foreign spillovers contribute to productivity growth, thereby facilitating the adoption of new technology. More specifically, we assume that foreign transactions lead to a sustainable growth in labor productivity in the home economy as domestic endowment of capital and technology increases. In accordance with the endogenous growth models, knowledge is viewed here as the ultimate driver of economic growth.[18]

III. Empirical analysis

Data

In the empirical analysis, our main data source is the new WIOD database, which provides a time-series of world input–output tables (WIOTs) from 1995 onwards. It covers 40 countries, including all EU-27 countries and 13 other major advanced and emerging nations. Data disaggregation includes 35 industries and 59 product groups. The 35 industries cover the overall economy and are mostly at the 2-digit NACE rev.1 level or their groups. The WIOD database provides information on the source (domestic industries and imports) and destination (intermediate use by domestic industries, domestic final demand or exports) of each product. For the purposes of this paper, a sample of 34 industries[19] for 10 Central and Eastern European countries[20] for the period 1995 to 2009 have been considered.

To analyze the role played by capital imports, as the main driver of technology diffusion, we define productivity as the value added per person employed. As mentioned earlier, foreign R&D will refer to the capital imports weighted by the exporter sector's R&D intensities. Capital imports account for the bilateral imports from the G7 countries[21] of the following industries: Machinery, NEC; Electrical and Optical Equipment; and Transport Equipment (Groups 29 to 35 according to the NACE rev.1). Exporter R&D intensities are constructed as the R&D expenditure over the value added for each aforementioned capital sector extracted from the OECD Science, Technology, and Patents database.

As a first approximation to our concern, Figures 3 and 4 display the scatter plots of value added per worker (measured in constant US$ and natural logarithms) against the R&D capital imports from the G7 countries (also in constant US$ and natural logarithms). Each point accounts for the pair

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[17] The increasing return on the production of technology drives the accumulation of technology and the economy grows indefinitely.
[18] See Liu (2008).
[19] See Table A2 in Appendix.
[20] Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia.
[21] Canada, France, Germany, Italy, Japan, United Kingdom, and United States.

labor productivity–R&D imports for a country and a sector in a certain year. For the whole sample, Figure 3 suggests a certain positive correlation between both variables. However, once we split the sample into two groups of more advanced (MA, hereafter) and less advanced (LA, hereafter), this positive relationship becomes clear for the case of the LA countries, but not for the MA (Figure 4).

Figure 3. Value added per worker-R&D imports relationship.
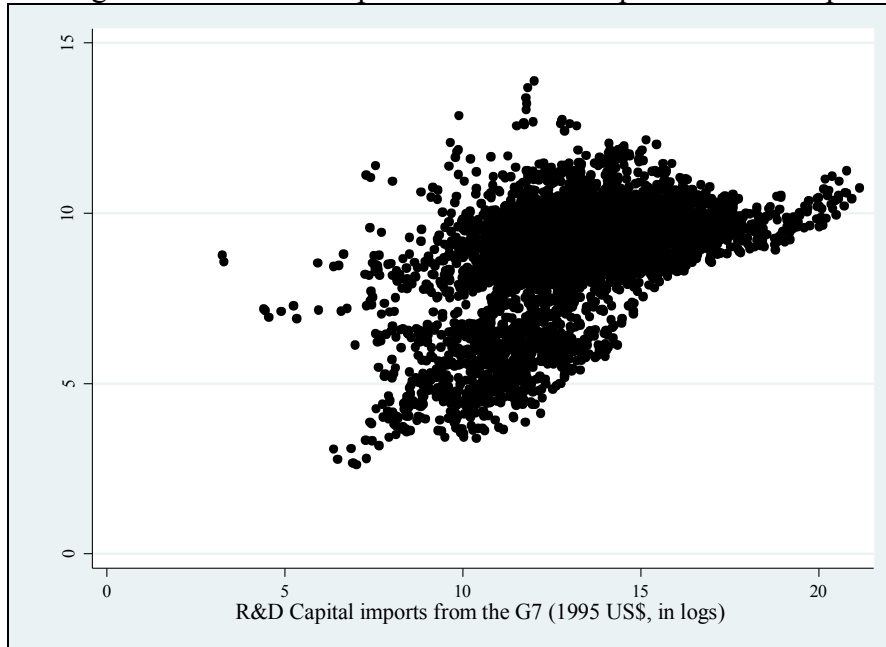
Source: Own elaboration.

Figure 4. Value added per worker-R&D imports relationship (by groups of countries).
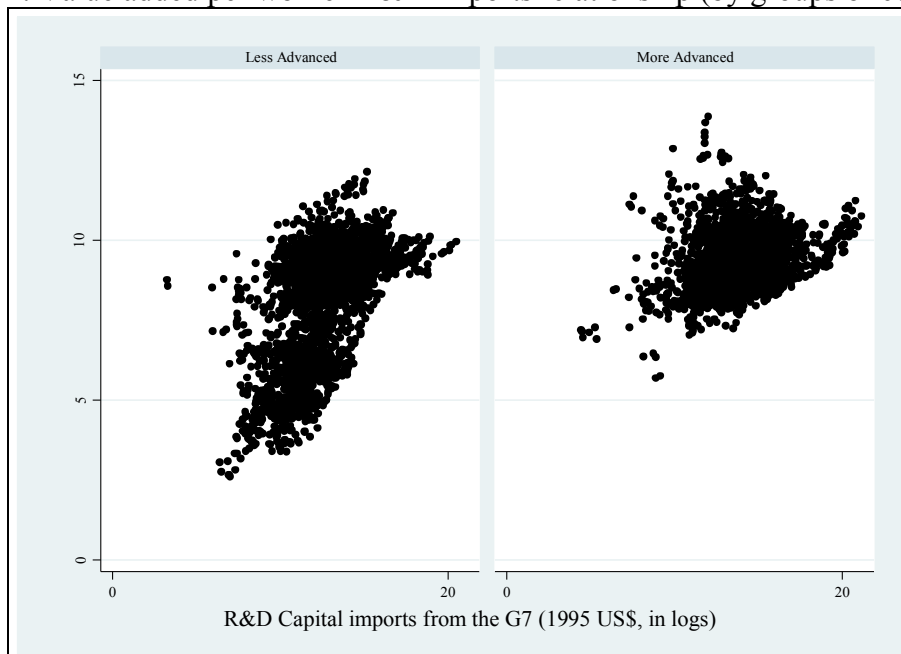
Source: Own elaboration.

Analogously to foreign R&D, domestic R&D is defined here as domestic intermediate capital inputs weighted by the domestic sector's R&D intensities, where domestic capital refers to the use of intermediate inputs from groups 29 to 35 (NACE rev. 1.1) by the 34 economic sectors considered. The country's distance to the technology frontier is measured by the ratio of its average productivity parameter to the global frontier parameter. To be more precise, in this study we define

the variable GAP, which we will refer to as the "distance" to the frontier, as the ratio of US labor productivity to the sample countries' labor productivity for each sector.

As we described previously, human capital can be defined as a composite index influenced by several factors. However, given the lack of human capital data at the sector level for these CEEs, we chose to create an indirect measure of human capital based on labor compensation. The WIOD database provides statistics on total labor compensation and the shares of high, medium, and low-skilled compensation. With these statistics we have constructed our human capital (*HK*) variable as follows:

$$HK_{ijt} = \frac{LAB_{ijt} \times LABHS_{ijt}}{EMPE_{ijt}}$$

where *LAB* is total labor compensation, *LABHS* represents the share of highly skilled labor compensation in the total compensation, and *EMPE* measures total employees. Subscripts *i*, *j* and *t* stand for country, sector and time, respectively. All monetary variables have been deflated to constant 1995 prices and converted to US$ using the price indexes and exchange rates delivered by the WIOD database.

Model specification and estimation method

To investigate the links between the transmission of foreign technology and productivity growth in the CEE countries empirically, we adopt two strategies. First, we estimate the growth rate of labor productivity based on equation (2). As shown previously in Section 3, this equation reflects the productivity growth enhancing effects of foreign transactions within an endogenous growth framework. More specifically, the rate of labor productivity growth is explained in this work by the lag of the per capita value added (lp_{t-1}), as a proxy of the convergence effect, the foreign source of technology (foreign R&D), domestic capital stock per worker, and other control variables that capture the country's capability to adopt foreign technology domestically: human capital, domestic R&D, and the technological gap.[22] Secondly, in order to check whether the results are similar to those obtained in previous empirical works, we estimate the level of labor productivity. In particular, we follow the Coe and Helpman (1995) approach. Assuming a Cobb-Douglas function, Coe and Helpman (1995) show the level of productivity as a function of knowledge capital with a domestic and a foreign component. This latter is measured as foreign R&D embodied in capital goods from industrial countries (Coe et al., 1997).

These equations are estimated using several panel data methodologies. Initially, we estimate the models through the traditional within-group estimator. The fixed-effects model allows us to control for the unobserved country and sector-specific effects, although it omits the potential endogeneity problem. For the sake of comparison and to deal with the problem of reverse causality or simultaneity, we then employ, on the one hand, the two-steps least squared (2SLS) instrumental variable method and, on the other, the system-generalized method of moments (GMM) approach for dynamic panel data proposed by Arellano and Bover (1995) and Blundell and Bond (1998). These methods enable us to consider both the presence of unobserved country- and sector-specific effects and to deal with the problem of reverse causality or simultaneity. More productive sectors may also need to import more capital goods. Thus, the potential positive impact of foreign transactions on productivity growth and the possibility of these flows being attracted by a higher rate of

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[22] In the endogenous growth models, the past income is usually employed as a proxy of initial efficiency that captures the convergence effect.

productivity growth are both plausible.[23] Ignoring this effect might lead to overstatement of the impact of foreign capital inflows and to finding spillovers where they do not exist.

IV. Econometric results

Productivity growth regressions

Table 3 shows the results for the basic model regressions for productivity labor growth. We initially present the aggregate effect of capital imports on productivity growth for the whole sample, considering the influence of local factors such as domestic R&D, domestic endowment of capital per person (*dk*), human capital (*hk*), and technological gap (*gap*). Later, in order to check if countries at different development stages benefit from different sources of foreign technology, we analyze the impact of these variables on labor productivity growth, distinguishing between MA and LA countries.[24]

INSERT TABLE 3 HERE

As can be appreciated, the estimations obtained confirm that once domestic local conditions and the technology gap are considered, imports of machinery and equipment from more advanced economies exert a positive and significant impact on productivity growth in the CEE countries. Moreover, on comparing the results reported separately for more and less advanced countries, we observe that although the influence of capital imports is positive and significant in both country groups, the coefficient on foreign technology is noticeably higher for LA countries than for MA countries. We also obtain the predicted negative and significant coefficient on the lag of the value added in all regressions, thus indicating the existence of a convergence effect. With highly significant and positive coefficients on *dk* and *hk* in all regressions, the above outcomes further support the positive relationship between domestic and human capital, and productivity growth. In the case of domestic R&D, although its coefficient is positive and significant in the within-group and GMM estimations, it is insignificant in the 2SLS estimation. Distance to the technology frontier seems also to affect productivity growth significantly (and with a negative sign). Accordingly, those countries that are far behind the technology frontier are expected to show a lower productivity growth. This effect, however, is greater among the more advanced countries than among the less advanced ones. This last outcome suggests that, once a country is sufficiently far behind the frontier, the loss in terms of productivity growth, of a step backwards, is lower than if the country were closer to the frontier.

Next, with the aim of exploring in greater depth the extent to which the success of knowledge diffusions is influenced by technological differences, we estimate an extended model including the interaction effects between the technology gap and both human capital, as proposed by Nelson and Phelps (1966), and foreign technology, as suggested by Glass and Saggi (1998). The results of these extended models are presented in Table 4.

INSERT TABLE 4 HERE

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[23] The endogeneity or reverse causality of R&D stocks has also been pointed out in other empirical works (see, for instance, Meriküll et al., 2013).

[24] As mentioned previously, here we have divided the sample into two groups according to the per capita GDP and R&D expenditure. Specifically, the group of more advanced countries comprises those CEE countries with relatively high GDP per capita data and with a per capita R&D expenditure (GERD) in 2012 above the EU27 average of 20%: Czech Republic, Estonia, Hungary, Slovenia, and Slovakia. The other group contains the less advanced countries with a per capita R&D expenditure in 2012 below the average of 20% for the EU27: Bulgaria, Latvia, Lithuania, Poland, and Romania.

Again, the initial productivity level and foreign R&D are statistically significant and with the expected signs, showing a strong convergence effect and an important role of capital imports in accounting for productivity growth in CEE countries. As in the previous estimations, domestic R&D shows a positive and insignificant effect on productivity growth in all regressions, except in the 2SLS estimations.

But more importantly, the results in the extended model confirm Glass and Saggi's hypothesis, according to which a larger productivity gap would limit the transfer of foreign technology. This result is highlighted by the negative and significant value of the interaction between the foreign R&D and gap variables. Our results, however, suggest evidence contrary to the Nelson-Phelps catch-up hypothesis. We find a statistically negative significant effect of the interaction between human capital and productivity distance, indicating that in countries that are closer to the technology frontier the speed of the technology catch-up rises with the level of human capital.[25]

Productivity level regression

In this section, we perform regressions for the level of labor productivity. The estimates presented in Table 5 confirm the existence of a positive influence of capital imports on productivity in the CEE countries, once industry- and country-specific effects and local conditions have been taken into account. As can be seen for the total sample, foreign R&D has a positive and significant coefficient in all regressions. Nevertheless, this effect is substantially higher for LA countries than for MA countries. Even in the GMM estimation, the positive influence of foreign R&D on labor productivity is only significant for the less developed economies. As in the previous estimates for productivity growth, domestic R&D, *dk* and *hk* are positive and highly significant in all productivity level regressions. Similarly, a higher distance to the technological frontier seems to diminish labor productivity, especially in the group of more advanced countries.

INSERT TABLE 5 HERE

The introduction of the interaction terms in Table 6 confirms the fact that the Glass and Saggi hypothesis holds in the level regressions, showing negative estimates for the interactions of foreign R&D with the technological gap. With negative and highly significant coefficients on the interaction of human capital with the gap, our results also reveal that a greater distance to the technology frontier will dismiss the productivity enhancing effect of human capital.

INSERT TABLE 6 HERE

Overall, our results support our idea that imports of machinery and equipment from more advanced economies exert a positive and significant influence on productivity growth in the CEE countries. Moreover, the beneficial influence of foreign technology depends on the level of development. They also corroborate the relevance of local conditions and particularly of domestic R&D, physical and human capital, and the distance to the technological frontier.

Conclusions

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[25] We have also estimated these equations with the gap variable together with their interaction terms. The results obtained for all explanatory variables are similar to those shown in Table 5, except for the coefficients on both interaction terms, which, although still negative and highly significant, have much smaller magnitudes. Results are available on request.

During the decade before the international crisis, productivity in CEE countries increased spectacularly, leading to an economic growth and a process of convergence toward the income of advanced industrial countries. As has already been shown by others, foreign sources of technology and R&D spillovers have played an extremely important role for these countries in their productivity growth.

In our paper, we focused on foreign technology diffusion through capital imports as the main determinant of this productivity growth, taking into account the fact that the domestic capability to benefit from productivity spillovers depends on local conditions. In particular, in the empirical analysis, and in accordance with the vast body of relevant literature, we considered domestic technology development and human capital as the main factors that contribute to the absorption of new technologies. We also analyze how the technology catch-up process (technology gap) influences the role of human capital and technology diffusion in enhancing productivity.

Our sample consisted of ten CEE countries over the period 1995-2009. As a novelty, we split the sample into two groups of countries based on economic development and R&D activity: "less advanced" and "more advanced" countries. We believe that disaggregated estimations might provide more accurate results about the different patterns of technology absorption. Our outcomes show that, when domestic conditions are controlled for, foreign technology is a significant source of productivity growth in the CEE countries, especially in the less advanced ones. The estimates also confirm that the size of the technology gap counts when it comes to succeeding in the absorption of foreign technology.

In sum, the findings in this work verify our hypothesis of the existence of important spillovers from foreign R&D, and particularly from capital imports, that benefit domestic efficiency. However, to implement incentives to stimulate foreign transactions it is not enough just to enhance productivity, since improving the level of skilled workers and domestic innovation should also be viewed as a prime guideline for policy makers. A greater human capital and domestic R&D will increase productivity both directly and indirectly through the reduction of the technology gap.

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Appendix

Table A1. Tertiary education indicators.

Gross graduation ratio from first degrees in tertiary education (%)*				Enrolment in tertiary education per 100 000 inhabitants		
	2000	2005	2012		2000	2005	2012
Bulgaria	18.5	23.6	35.1	Bulgaria	3325.6	3151.5	4020.9
Czech Rep.	14.1	24.7	41.6	Czech Rep.	2520.7	3354.8	4247.3
Estonia	9.7	30.1	25.2	Estonia	4014.6	5232.9	5398.8
Hungary	27.8	44.1	30.0	Hungary	3068.2	4411.8	3928.1
Latvia	42.6	47.2	41.3	Latvia	3928.0	6003.6	4851.5
Lithuania	22.0	39.2	44.0	Lithuania	3555.7	6062.2	5945.0
Poland	35.7	42.5	58.1	Poland	4196.8	5645.4	5396.2
Romania	16.2	30.0	46.7**	Romania	2065.9	3396.8	5589.2**
Slovakia	21.0	29.7	43.9	Slovakia	2569.4	3423.9	4159.9
Slovenia	16.2	22.4	52.4	Slovenia	4305.2	5718.9	5183.3
EU average	24.5	32.9	39.2**	EU average	3302.9	4056.4	4355.9

Source: UNESCO Institute for Statistics http://data.uis.unesco.org/.

Note: *All graduates in first degree programs expressed as a percentage of the population of the age at which they theoretically finish the most common first degree program in the given country. ** Data for 2011.

Table A2: Sectors of activity

Code	Name	Code	Name
AtB	Agriculture, hunting, forestry and fishing	F	Construction
C	Mining and quarrying	G50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
DA15t16	Food, beverages and tobacco	G51	Wholesale trade and commission trade, except for motor vehicles and motorcycles
DB17t18	Textiles and textile	G52	Retail trade, except for motor vehicles and motorcycles; repair of household goods
DC19	Leather and footwear	H	Hotels and restaurants
DD20	Wood and products of wood and cork	I60	Other Inland transport
DE21t22	Pulp, paper, printing and publishing	I61	Other Water transport
DF23	Coke, refined petroleum and nuclear fuel	I62	Other Air transport
DG24	Chemicals and chemical products	I63	Other Supporting and auxiliary transport activities; activities of travel agencies
DH25	Rubber and plastics	I64	Post and telecommunications
DI26	Other non-metallic minerals	J	Financial intermediation
DJ27t28	Basic metals and fabricated metal products	K70	Real estate activities
DK29	Machinery, NEC	K71t74	Renting of m&eq and other business activities
DL30t33	Electrical and optical equipment	L	Public admin and defense; compulsory social security
DM34t35	Transport equipment	M	Education
DN36t37	Manufacturing, NEC; Recycling	N	Health and social work
E	Electricity, gas and water supply	O	Other community, social and personal services

Source: Own elaboration

TABLES

Table 3. Growth of value added per worker. Basic model. 1995-2009.

Explanatory variable	Within-group			2SLS			System GMM		
	Total	MA countries	LA countries	Total	MA countries	LA countries	Total	MA countries	LA countries
va(-1)	-0.784***	-0.819***	-0.778***	-0.221***	-0.199***	-0.246***	-1.081***	-1.165***	-0.952***
	(0.012)	(0.015)	(0.019)	(0.010)	(0.012)	(0.017)	(0.017)	(0.013)	(0.017)
foreign R&D	**0.061*****	**0.049*****	**0.107*****	**0.026*****	**0.023*****	**0.024***	**0.068*****	**0.056*****	**0.105*****
	(0.007)	**(0.008)**	**(0.015)**	**(0.005)**	**(0.006)**	**(0.015)**	**(0.009)**	**(0.010)**	**(0.018)**
domestic R&D	0.008	0.025***	0.055***	-0.008	-0.008	-0.002	0.036***	0.030***	0.048***
	(0.006)	(0.007)	(0.011)	(0.005)	(0.006)	(0.014)	(0.007)	(0.008)	(0.013)
dk	0.303***	0.288***	0.449***	0.093***	0.074***	0.118***	0.553***	0.460***	0.764***
	(0.012)	(0.015)	(0.022)	(0.006)	(0.007)	(0.012)	(0.017)	(0.017)	(0.027)
hk	0.385***	0.435***	0.282***	0.109***	0.078***	0.108***	0.250***	0.414***	0.061***
	(0.012)	(0.015)	(0.017)	(0.005)	(0.007)	(0.009)	(0.012)	(0.019)	(0.017)
gap	-0.026***	-0.101***	-0.011**	-0.019***	-0.052***	-0.011**	-0.143***	-0.139***	-0.009***
	(0.005)	(0.011)	(0.001)	(0.005)	(0.001)	(0.001)	(0.001)	(0.017)	(0.001)
N obs	3124	2242	882	3124	2242	882	3124	2242	882
Endogeneity test	-	-	-	50.60	15.46	61.35	34.29	11.96	27.49
				[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]

Source: Own elaboration.
Notes: Robust standard errors are in parentheses. *, **, *** denote significance at the 10%, 5% and 1% levels, respectively. All estimations include a constant term and a year variable. The methods used for the Endogeneity tests are the Wu-Hausman test and the Difference-in-Sargan test (C test) for the IV and GMM estimations, respectively. We report the p-values of these tests in brackets.

Table 4. Growth of value added per worker. Model with interactions terms. 1995-2009.

Explanatory variable	Within-group			2SLS			System GMM		
	Total	MA countries	LA countries	Total	MA countries	LA countries	Total	MA countries	LA countries
va(-1)	-0.797***	-0.820***	-0.785***	-0.230***	-0.200***	-0.264***	-1.111***	-1.169***	-0.957***
	(0.012)	(0.015)	(0.019)	(0.010)	(0.012)	(0.017)	(0.011)	(0.013)	(0.013)
foreign R&D	**0.059***	**0.051***	**0.099***	**0.027***	**0.024***	**0.036**	**0.066***	**0.060***	**0.089***
	(0.007)	**(0.008)**	**(0.015)**	**(0.005)**	**(0.006)**	**(0.015)**	**(0.009)**	**(0.009)**	**(0.017)**
domestic R&D	0.009	0.026***	0.055***	-0.009	-0.0099	-0.008	0.039***	0.032***	0.052***
	(0.006)	(0.007)	(0.011)	(0.005)	(0.006)	(0.014)	(0.005)	(0.007)	(0.012)
dk	0.303***	0.282***	0.447***	0.096***	0.075***	0.122***	0.531***	0.436***	0.724***
	(0.012)	(0.015)	(0.022)	(0.006)	(0.007)	(0.012)	(0.016)	(0.017)	(0.029)
hk	0.406***	0.441***	0.304***	0.113***	0.079***	0.1116***	0.324***	0.444***	0.117***
	(0.012)	(0.015)	(0.017)	(0.005)	(0.007)	(0.009)	(0.013)	(0.019)	(0.021)
*hk*gap*	-0.029***	-0.016**	-0.018**	-0.019***	-0.007	-0.004***	-0.103***	-0.075***	-0.027***
	(0.003)	(0.008)	(0.003)	(0.003)	(0.010)	(0.001)	(0.001)	(0.001)	(0.001)
*foreign R&D *gap*	-0.016***	-0.017***	0.008***	-0.009***	-0.008***	-0.010	-0.054***	-0.033***	-0.012**
	(0.001)	(0.002)	(0.001)	(0.001)	(0.003)	(0.004)	(0.001)	(0.001)	(0.001)
N obs	3124	2242	882	3124	2242	882	3124	2242	882
Endogeneity test	-	-	-	50.50	15.95	55.71	33.72	12.06	25.23
				[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]

Source: Own elaboration.

Notes: Robust standard errors are in parentheses. *, **, *** denote significance at the 10%, 5% and 1% levels, respectively. All estimations include a constant term and a year variable. The methods used for the Endogeneity tests are the Wu-Hausman test and the Difference-in-Sargan test (C test) for the IV and GMM estimations, respectively. We report the p-values of these tests in brackets.

Table 5. Value added per worker. Basic model. 1995-2009.

Explanatory variable	Within-group			2SLS			System GMM		
	Total	MA countries	LA countries	Total	MA countries	LA countries	Total	MA countries	LA countries
foreign R&D	**0.100*** **	**0.085*** **	**0.148*** **	**0.066*** **	**0.024**	**0.063*** **	**0.015***	**-0.001**	**0.069*** **
	(0.008)	**(0.008)**	**(0.015)**	**(0.009)**	**(0.026)**	**(0.010)**	**(0.008)**	**(0.010)**	**(0.012)**
domestic R&D	0.013**	0.026***	0.041***	0.008	0.004	0.058**	0.055***	0.045***	0.089***
	(0.007)	(0.008)	(0.012)	(0.005)	(0.025)	(0.691)	(0.007)	(0.008)	(0.009)
_dk_	0.419***	0.383***	0.570***	0.439***	0.519***	0.417***	0.619***	0.4997***	0.809***
	(0.012)	(0.014)	(0.019)	(0.007)	(0.015)	(0.009)	(0.015)	(0.017)	(0.024)
_hk_	0.453***	0.491***	0.336***	0.335***	0.248***	0.347***	0.242***	0.359***	0.074***
	(0.011)	(0.014)	(0.017)	(0.008)	(0.016)	(0.011)	(0.013)	(0.017)	(0.016)
gap	-0.038***	-0.139***	-0.016**	-0.097***	-0.067**	-0.245***	-0.089***	-0.073***	0.008
	(0.005)	(0.011)	(0.005)	(0.008)	(0.008)	(0.022)	(0.011)	(0.020)	(0.008)
N obs	3364	2413	951	3126	2243	882	3364	2413	951
Endogeneity test	-	-	-	50.60	15.46	61.35	34.29	11.96	27.49
				[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]

Source: Own elaboration.
Notes: Robust standard errors are in parentheses. *, **, *** denote significance at the 10%, 5% and 1% levels, respectively. All estimations include a constant term and a year variable. The methods used for the Endogeneity tests are the Wu-Hausman test and the Difference-in-Sargan test (C test) for the IV and GMM estimations, respectively. We report the p-values of these tests in brackets.