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International R&D Spillovers in Transition Countries: The Impact of Trade and Foreign Direct Investment

by

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Abstract

While the economic theory predicts that developing countries will gain the most from technology spillovers, there have been only a few analyses looking at this question empirically. The present study focuses on a panel of 27 transition and 20 Western European countries between 1990 and 2006 and uses the latest developments in panel unit root and cointegration testing to disentangle the effects of international spillovers via trade and FDI. My findings show that imports remain the main channel of diffusion for both sets of countries, while FDI, although significant econometrically, has less quantitative impact on domestic productivity. The domestic R&D capital stock plays an active role in Western Europe while in the Eastern part is much less important. Human capital has an overall robust positive influence on TFP. The results confirm that transition countries seem to gain more in terms of productivity from the international diffusion process than their Western counterparts.

JEL classification: O30; O47; O57; C23; D24
Keywords: technology spillovers; trade; investment; panel cointegration;

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1. Introduction

Over the last decade studies by Prescott (1998), Hall and Jones (1999) or Easterly and Levine (2001) have demonstrated that the variation in economic growth rates among countries is explained largely by differences in technological improvements rather than human or capital accumulation. Given that a handful of rich industrialized countries account for most of the world's new technology creation, the developing ones rely mostly on technological spillovers from abroad[1] (Keller, 2004; Saggi, 2002, Eaton and Kortum, 1999). An important strand of literature concerned with the mechanisms through which these R&D spillovers occur has consecrated the role of trade and FDI as main channels for technological diffusion (Coe and Helpman, 1995; Xu, 2000; Van Pottelsberghe de la Potterie and Lichtenberg, 2001). Although FDI has grown tremendously over the last decades under the auspices of globalization, it remains under-represented in most of the empirical studies. Moreover, a substantial deficit of this literature is the small number of studies looking at the potential effects for developing countries, even though economic theory identifies them as the main winners of this process.

This study attempts to fill this gap and contributes to the literature as follows. First, I analyze for the first time the process of technological diffusion in transition countries. Although a small number of studies (Coe et al., 1997; Mayer, 2001; Crispolti and Marconi, 2005; Ciruelos and Wang, 2005) have included developing nations in their sample, the former communist countries of Eastern Europe and Central Asia remain uncovered. Moreover, unlike previous studies, I include their domestic R&D stock as control variable in the estimations. Secondly, I employ both FDI and imports as possible channels of diffusion. Since, in most cases, FDI and trade seem to be complements rather than substitutes, it is important for an efficient estimation of their effects to include both of them in the analysis. Thirdly, I provide comparisons between a richer Western Europe and its poorer Eastern neighbors in order disentangle the efficiency of these channels and their inherent differences in this process. Furthermore, pooling together developed with developing nations may yield ambiguous results, while the effects of FDI or trade may be very different in each case (Bloningen and Wang, 2005). Finally, in order to avoid spurious regressions, I use panel cointegration and dynamic OLS analysis to obtain the long run relationship between total factor productivity and R&D spillovers.

Understanding the mechanisms and channels of technology diffusion across countries in today's increasingly integrated world has become a crucial issue for policy makers from developing/transitional countries. As a result of this phenomenon, economic growth depends more and more on a country's portfolio of trade and investment partners. While for world's innovative leaders technology diffusion may tweak ambiguously their incentives for R&D investment, developing countries are expected only to gain in all scenarios. By engaging in economic activities with foreign partners, under certain conditions, countries can access their knowledge stock at a lower cost than the one occurring if it would have developed that same knowledge internally.

The paper is organized as follows. The next section provides a comprehensive overview of the literature. The third section introduces the theoretical and empirical model for this study. The fourth section presents the main features of the data while the

[1]In 2004, 81.32 percent of the world's R&D spending originated from OECD countries while the rest of the world accounted for only 18.67 percent (in constant PPP terms, own calculations)

fifth reports the econometric analysis (unit roots and cointegration tests, regression estimations) and results. Section six provides additional robustness check tests while section seven concludes.

2. Literature review

Technology diffusion is a topic widely explored in the recent economic literature. While there are still debates with respect to specification and measurements issues or methodological biases, the bulk of studies seem to agree on a couple of key issues. First, all countries benefit from foreign invented technology through spillovers. A strong argument in this way is the skewed distribution of R&D inputs and outputs, concentrated in few industrialized countries. Secondly, there are both barriers and facilitating factors for technology (natural or human related) that impact the amount of learning and absorption taking place (Xu and Chiang, 2005). Finally, in empirical approaches each specification has particular trade-offs but overall the studies seem to convergence to similar results. In this section I am going to provide a comprehensive overview of the theoretical and empirical developments in these strains of literature.

Trade

Trade can help technology diffusion in a number of ways: it opens up the channels of communication for transmission of technical information, reduces duplication of research through encouragement of new differentiated products and enhances competition and efficiency of allocation through enlargement of available markets (Grossman and Helpman, 1991). The three types of factors that influence the process of technological transfer among countries through trade can be summarized as: the effort to transfer these technologies, the existing absorptive capacity in the recipient country and the differences between it and the donor (Hoppe, 2005).

There are a handful of theoretical models of technological diffusion constituting the backbone of the empirical literature that has emerged in the last years. Grossman and Helpman (1990) prove that not only the domestic R&D but also foreign R&D contributes to the formation of the local knowledge capital. Nelson and Phelps (1966) postulate that the technological level depends on the human capital available and the distance from the technological frontier, emphasizing the role of the latter while the Rivera-Batiz and Romer (1991) model has a knowledge production function depending on the existing knowledge stock and the human resources involved. However, a gap still exists between the well behaved theoretical models and the empirical strains of literature constrained by measurement and data availability issues.

The empirical work at the macro level is quite diverse. It focuses mostly on developed countries and considers various specifications (channels of diffusion, control variables and levels of analysis). The seminal contribution of Coe and Helpman (1995) (henceforth CH) emphasized the role of trade as a transfer mean of R&D between OECD countries while a later study finds similar effects from advanced to less advanced technological countries (Coe et al., 1997). They relate TFP to both domestic and foreign R&D using as measures for this effect trade weighted R&D stocks. Keller's study (1998) contests their methodology, pointing out that using "random" assigned trade shares one still achieves significant spillovers. However, in their reply, Coe and Hoffmaister (1999) show that their spillover measure is valid and robust and the results become insignificant when using random trade shares[2]. Lichtenberg and Pottelsberghe (1998) (henceforth LP) brought some positive criticism towards the CH paper in correcting a possible bias by using ratios of R&D stocks to GDP (intensity measure) rather than raw numbers. However, despite their different specification, the spillovers resulted are quite similar to the results reported by CH. Furthermore, under the non-stationary hypothesis of the variables employed by CH, Kao et al. (1999) use different estimation procedures (Fully Modified OLS and Dynamic OLS) to construct valid t-statistics and standard errors. Using these econometrically superior estimators, they do not find significant knowledge spillovers through trade casting some doubts on the validity of CH's results. Lee (2006) shows that the significance of trade spillovers is sensitive to the specification used (CH or LP) and using the same estimation as Kao et al. (1999) find out that LP specification remains significant even when using DOLS or FMOLS. Finally, the CH or LP analysis focuses on "direct" R&D spillovers, given by the levels of R&D *produced* by a portfolio of trading partners, while missing out the "indirect" spillovers given by the *available* R&D. A country X gains from country's Z technological stock even it might not import directly from it but from another country Y. If Y imports from Z its *available* R&D stock is greater than the *produced* one and this increases the spillovers going to X as well. Lumenga-Neso et al. (2004) argue that such a model performs better that CH or Keller's, supporting these "indirect" spillovers[3].

Getting deeper with their analysis, Xu and Wang (1999) compare the effects of capital versus non-capital goods trade, concluding that the former is a more significant diffusion channel due to its high tech content. This result is confirmed by subsequent work using imports of machinery goods to measure trade spillovers (Eaton and Kortum, 2001; Xu and Chiang, 2005). Recently, Acharya and Keller (2007) take at the industry level in 17 OECD countries emphasizing the role of technological transfer on productivity, often surpassing the one of domestic R&D. Their findings show significant asymmetries in the transfer patterns due to both geography and trade patterns, fact that can be tighten to domestic investment in R&D or education levels.

Foreign Direct Investment

FDI has been considered for a long time an important channel for technological diffusion on the basis that foreign firms transfer their technology between multinational parents and their subsidiaries. This generates high competition among regions or states in attracting the FDI, making these contingent spillovers an important policy issue as well.

However, the early studies (Konings, 2000; Aitken and Harrison, 1999) using micro data have founded negative or no effects (Kinoshita, 2000; Gorg and Greenaway, 2003) of FDI on domestic productivity in developing countries like Bulgaria, Romania and respectively Venezuela. Among possible explanations they have listed: (i) a strong

[2] They claim that Keller's random weights are just simple averages with a random error and when using alternative random weights the spillovers are not existent, as expected.
[3] However, their estimated elasticity of TFP with respect to "indirect" spillovers are not very different from the CH's ones using the "direct" spillovers only.

negative competition effect dominating positive spillovers; (ii) "crowding out" the market by foreign investors raising the average costs for domestic producers; (iii) the spillovers are mainly vertical between plants and supplier; (iv) FDI tends to flow in more productive sectors of an economy, thus, the observed effect is not causal. Nevertheless, the recent evidence tends to be more optimistic. Haskel et al. (2002) and Griffith et al. (2004) looking at the inward FDI in UK using micro data find out such positive but rather small effects. Keller and Yeaple (2005) find large impacts concluding that about 11 percent of the US manufacturing productivity growth can be accounted from FDI. Van Pottelsberghe de la Potterie and Lichtenberg (2001) explore the validity of FDI spillovers in the OECD context, identifying as significant channels imports and outward foreign investment, but surprisingly, not the incoming FDI[4]. Damijan et. al (2003) analyze a panel of 8,000 firms for ten advanced transition countries from Eastern Europe over the period 1995 to1999. He concludes that FDI effects are significant in five of the ten countries analyzed and gives a bigger importance to the vertical spillovers. Crispolti and Marconi (2005) examine technology diffusion from the TRIAD (USA, Japana and EU) in 45 developing countries from Asia, Africa and Latin America over the time 1980 to 2000. Using a FMOLS (fully modified OLS) estimator they find trade and FDI spillovers to contribute significantly to the TFP growth of the countries in the sample. Finally, Ciruelos and Wang (2005) look at a sample of 57 (20 OECD and 27 developing) countries from 1998 to 2001 and find that both FDI and trade serve as a channel for technology diffusion in less developed countries that possess a critical mass of human capital.

Other

In addition to the channels discussed above, there are various other means through which technology can flow between countries: exports, outward FDI, capital and human mobility, scientific publications or conferences, patenting or licensing. First, most of them cannot be properly quantified due to data availability and econometric estimation issues. Furthermore, in the case of those for which data is available (exports, outward FDI) the empirical support is extremely weak (Keller, 2004). Thirdly, there are great difficulties in putting together comparable data for most of the possible channels listed above for both developed and developing countries. Finally, as Griliches (1979) points out, including too many channels in the analysis yields estimation problems (multicollinearity) which makes them less desirable.

3. Theoretical and empirical model

The empirical specification follows the main direction of CH while augmented by the subsequent literature (Borensztein et al., 1998). Technological progress takes place in a country as a result of a "capital deepening" process in the form of an increase of the capital goods available. The final output is produced using a variety of intermediate inputs produced by both domestic and foreign firms. Foreign firms are assumed to be technologically advanced and they produce new varieties of intermediate goods at a lower cost. These can be obtained via trade (imports) or FDI when the foreign firms

[4] Similarly to Xu and Wang (1999).

decide to invest abroad to exploit the lower operational costs in domestic markets. The latter depends also on the quality of available human capital in these markets. Hence, the model emphasizes the two main channels of technology diffusion as well as requirements for an absorptive capacity.

In these technology diffusion models, the variety of intermediate goods available for production increased with the R&D investment, while the foreign R&D can diffuse from the technologically advanced countries to the others, increasing their productivity. More specific and building on the CH weighting scheme for foreign R&D spillovers (eq. 1, p. 863), the total factor productivity of a country i in time t is given by the following linear specification which I will refer to as the *basic model*:

$$\log A_{i,t} = \alpha_i + \beta_1 \log S_{it}^{FDI} + \beta_2 \log S_{it}^{TRADE} + \beta_3 X_{it} + \varepsilon_{it} \qquad (1)$$

where $\log A_{i,t}$ is the logarithm of total factor productivity in country i (recipient) and year t. α_i represents a country-specific constant term. S_{it}^{FDI} and S_{it}^{TRADE} represent the technology spillovers to country i via trade and FDI originating from country j. X_{it} is a vector of control variables. The spillover variables are computed as follows:

$$S_{it}^{FDI} = \sum_{j-1}^{m} s_{jit}^{FDI} * FRD_{jt} \qquad i = 1, n; i \neq j; j = 1, m; \qquad (2)$$

$$S_{it}^{TRADE} = \sum_{j-1}^{m} s_{jit}^{TRADE} * FRD_{jt} \qquad i = 1, n; i \neq j; j = 1, m; \qquad (3)$$

where s_{jit}^{FDI} (s_{jit}^{TRADE}) represent the share of inward FDI (imports) of country i originated from country j in year t as a percentage of the total outward FDI (exports) of country j in that year. FRD_{jt} represents the stock of R&D of country j in the same year (t). Hence, s_{jit}^{FDI} (s_{jit}^{TRADE}) is the FDI (trade) weighted foreign R&D stock that accounts for the technological spillovers through inward FDI (imports). As control variables I include measures of domestic R&D stock (DRD_{jt}), human capital (HK_{jt}) and government expenditure (GOV_{jt}) that are presented in the literature as major influences on TFP and growth.

The degree of openness of an economy has a crucial role in facilitating the technology transfer. In order to differentiate between spillovers in countries with identical s_{jit}^{FDI} (s_{jit}^{TRADE}) but very different degrees of openness to foreign investment (trade) and give more weight to those more open to FDI (trade), I employ an *alternative model*. Further developing the CH specification (eq. 2, p. 863), I include two additional measures that take into account a country's openness to foreign investment (trade). In this case the estimation becomes:

$$\log A_{i,t} = \alpha_i + \beta'_1 \log S'^{FDI}_{it} + \beta'_2 \log S'^{TRADE}_{it} + \beta_3 X_{it} + \varepsilon_{it} \qquad (4)$$

$$S'^{FDI}_{it} = fdi\_open_{it} * \sum_{j-1}^{m} s_{jit}^{FDI} * FRD_{jt} \qquad i = 1, n; i \neq j; j = 1, m; \qquad (5)$$

$$S'^{TRADE}_{it} = trade\_open_{it} * \sum_{j-1}^{m} s_{jit}^{TRADE} * FRD_{jt} \qquad i = 1, n; i \neq j; j = 1, m; \qquad (6)$$

where fdi_open_{it} ($trade\_open_{it}$) represents country's i openness to FDI computed as the total inward FDI (imports) over GDP. The vector of control variables (X_{it}) remains the same. As robustness check measures and to accommodate some of the criticisms (Keller, 1998; LP) I am going to perform additional regression using the LP weighting scheme in Section 6.

In the above estimations it is also crucial to establish the relationship between trade and FDI. This liaison is a very complex one. Theory emphasizes both a substitution (general equilibrium trade models or abstract FDI explanatory approaches) and a complementarity relationship (models with vertical MNCs and demand considerations). However, empirically most of the work indicates complementarity, which makes our estimation legitimate. For an overview of these issues see the survey by Forte (2004).

To obtain an accurate estimation of the elasticities of spillovers, I include a series of control variables, some of which present also policy interest. Previous studies analyzing productivity improvements have all emphasized the crucial role of *domestic R&D investment* or stock (Griliches, 1979). Thus, in order to estimate correctly the effect of spillovers from abroad it must be included in the regression analysis. Moreover, a certain level of *human capital* is needed to absorb efficiently the available technology (Nelson and Phelps, 1966; Benhabib and Spiegel, 1994), while high skilled labor force impacts productivity directly as well (Engelbrecht, 2002). Countries differ among themselves also in terms of *investment rates* which may enhance or prohibit also the inward flows of FDI and trade[5]. While the mean investment share of GDP in Central and Eastern Europe is 15.43 percent, the obvious extremes are in Central Asia (10.68 percent) and the developed West (21.56 percent). Although the effects and causality of *government expenditure* on growth are still a subject of debate in the literature (Easterly and Rebelo, 1993; Barro, 1990; Devarajan et al., 1996; Gupta et al., 2005), there seems to be a strong relationship between the two. While this study is less concerned with the question above, I would like to control for the possible effects of government expenditure on TFP in a sample that contains both developed and developing countries.

The main interest of this work remains the sign and magnitude of the spillovers from trade and foreign investment. I formulate some hypotheses about the variables included in the model: (i) both β_1 and β_2 (as well as β'_1 and β'_2) are positive and significant, signalling that FDI and trade are important channels for technology diffusion; (ii) human capital plays a significant role both in Eastern and Western Europe; (iii) the function of R&D stocks is different in these two sub-samples, while developed Western Europe is an engine for innovation and science, the Eastern European stocks are smaller and outdated (Krammer, 2007); (iv) foreign spillovers from FDI and trade are having a bigger positive impact on domestic productivity in the case of transitional countries.

[5] A country with a high investment share is more attractive to the foreign investors and will grow at a higher rate which in turn will also boost trade and FDI.

4. Data

This paper employs a panel of 47 countries over the period 1990-2006[6]. From them, 20 are developed Western European while the rest are transitional countries: 19 from Central and Eastern Europe and 8 from Central Asia (former USSR). The time span coincides with the beginning of the latter's transition process from a centralized economy towards a free market one. As the source for technology spillovers, I use the 25 OECD countries and analyze the flows between OECD25 and Western Europe on one hand, and Eastern transitional countries on the other, with the purpose of emphasizing differences and similarities between them. Further details, beyond the ones presented in this section, on the data, definition of variables and sources are provided in Annex A.

4.1 Total Factor Productivity

TFP is measured as the residual from the aggregated output production function using the country's stock of capital, labor force and output. More specific: $\log A_{it} = \log Y_{it} - \alpha \log K_{it} - \beta \log L_{it}$. Assuming constant returns to scale, I use the labor and capital shares of 0.65 and 0.35, frequently employed in the literature (CH; Xu and Chiang, 2005; Ciruelos and Wang, 2005) and validate them empirically[7]. In addition, as a robustness check measure I use the actual shares of capital and labor income reported in the last column of Table 1. These shares are highly correlated (0.80 correlation coefficient) and using this robust measure of TFP yields very similar results (not reported here due to space constraints but available upon request). Data on total GDP and employment comes from the Groningen Growth and Development Centre and the Conference Board, Total Economy Database. The physical capital stock values are computed using data on aggregate investment share as a percentage of GDP from the World Table Version 6.2 using the perpetual inventory method.

4.2 R&D capital stocks

The estimates of domestic R&D capital stock are based on the gross expenditure on R&D (GERD) which includes both the business sector spending and the public R&D from universities or research institutes. In the case of the countries of origin for spillovers (OECD25) the data comes from OECD's Main Science and Technology Indicators 2007 while for transition countries I reconstruct the R&D stocks using data on GERD as a percentage of GDP (from UNESCO Statistical Yearbooks, Eurostat and national statistics offices) and GDP (World Development Indicators 2007). To compute these stocks I employ again the perpetual inventory method.

4.3 Foreign R&D stocks embodied in imports

[6] Due to their treatment in the official statistics prior to 1995, Belgium and Luxembourg are aggregated into one entity (BLEU – Belgium-Luxembourg Economic Union)

[7] I also perform a parametric estimation of these coefficients using a Cobb-Douglas production function log-differentiated and second and third lags of the explanatory variables as instruments in an instrumental variables (IV) regression. The results come very close to this assumption: $\Delta Y = 0.33\ \Delta K + 0.59\ \Delta L$, with both coefficients highly significant ($p<0.000$) and a high R squared (0.88).

The R&D spillovers from OECD25 are computed following equations (3) for the basic model and (6) for the alternative one that emphasizes openness to trade. Bilateral trade flows are taken from IMF's Direction of Trade 2007 (DOTS). The weights used for R&D stocks represent countries i (recipient) import share of the total exports of country j (OECD25, donor). Openness to trade is computed as the ratio of imports to gross domestic product using DOTS data on imports and GDP data from World Development Indicators 2007.

4.4 Foreign R&D stocks embodied in FDI

The FDI spillovers are computed in a similar manner with the trade related ones following equations (2) and respectively (5). Detailed inward FDI flows are procured from the individual statistics of each of these 25 OECD countries as reported in the annexes of the UNCTAD World Investment Report 2007. These are usually given in national currency and current dollar figures but this is acceptable since I am not interested in absolute levels but percentages. The main advantage of using this data compared with the commonly used OECD International Direct Investment Statistics is their superior time consistency. The main drawback is the extent of coverage: usually these tables present data from early 1990s until 2003-2005, so the latest years are not included.

4.5 Human capital measures

As a proxy for the human capital available in a country I use two measures. The first is from the widely employed Barro and Lee (1996) dataset and its updated 2000 version. This index covers also some of the transitional countries and reports the average years of secondary schooling in male population over 25 years old over five-year periods. While the coverage is very good for Western states, the rest have numerous missing observations. The data confirms the high quality of human capital available in transitional countries: the average years of schooling are 9.33 for Central Asia (34 observations), 8.93 for Eastern Europe (289 obs.) and 8.44 for Western (340 obs.) The second measure of human capital that I use is the tertiary enrollment as a percent of the gross. Yearly values of this indicator come from World Development Indicators 2007 but the main problem is the missing observations in the first half of the 1990s. Western Europe has a tertiary enrollment rate of 43 percent of the gross, while Eastern Europe (36.99%) and Central Asian (26.40%) countries are quite close to its level. Finally, due to the better coverage of the latter measure, I use it as my primary human capital variable, while the Barro-Lee variable is included as robustness checks in auxiliary regressions.

4.6 Investment share and government share of GDP

The investment and governments shares of GDP are taken from World Penn Tables 6.2 between 1990 and 2004. These shares are obtained by dividing each of these components to the real gross domestic product. The data confirms "Wagner's law", according to which the government expenditures tend to increase with the development of an industrial economy: Central Asia (10.68%), Eastern Europe (15.43%) and Western Europe (21.56%).

5. Empirical Analysis

Table 2 presents the descriptive statistics for the variables employed in this study. Before proceeding to the actual estimation of the spillovers, I would like to make sure that the analysis doesn't suffer from major flaws. The first concern is the multicollinearity problem which could be a major obstacle in estimation of international technological spillovers since many macro aggregated series are closely related (Griliches, 1979). Similar to others (Lee, 2006) the correlation matrix (Table 4) exhibits only one high pair wise correlation (0.85). However since this does not exceed the critical tolerance level implied by the literature (0.90), blow up the standard errors of the estimates in the same regression or impacts significantly the estimated coefficients, I conclude that multicollinearity is not an issue in this case. In order to stay away from such problems, I also restrain from using excessive control variables.

The second concern refers to the econometric properties of the variables in the dataset. CH, LP or Ciruelos and Wang (2005) derive their estimations using OLS regressions. However, estimating a relationship between non-stationary variable using standard OLS techniques may yield spurious results. CH have recognized this issue and attempted to derive a long run relationship between TFP and foreign R&D spillovers via trade but their cointegration hypothesis was rejected. Advancements in panel unit root testing since then allow now for better estimations and tests. Lichtenberg and van Pottelsberghe (2001) based on the LP and CH studies find a cointegrated relationship. Recent papers make the case by employing a variety of such tests (Crispolti and Marconi, 2005; Lee, 2006; Zhu and Jeon, 2007).

The present econometric literature proves that panel unit root and cointegration tests have higher power than unit root tests based on individual time series especially when the latter are not very long. These tests are classified on the restrictions of the autoregressive process between the cross-sections. Hence, we have tests that assume a cross-sectional common unit root (Breitung, 2000; Hadri, 2000; Levin, Lin and Chu, 2002) while the tests proposed by Maddala and Wu (1999), Im, Pesaran and Shin (2003) allow for individual unit root processes across sections[8]. The outcomes of these tests are presented in Table 3. The overall results clearly show that the variables included in the analysis are not stationary.

To determine if the regression results of the estimated equations are spurious, I need to determine if there is a cointegration relationship between the employed variables. The Engle-Granger cointegration test is based on examination of the residuals of a regression with I (1) variables. If these variables are cointegrated the error term should be stationary or I (0). Pedroni (1999, 2004) and Kao (1999) extend the Engle-Granger approach to panel structured data. The results of from these tests are reported in Table 5. Both indicate clearly that the null hypothesis of no cointegration in all these specifications can be firmly rejected.

[8] Also these tests differ in terms of the autocorrelation correction method used: B, IPS and LLC involving regressions on lagged difference terms while H, LLC involve kernel weighting.

Given that there is a cointegrated relationship between the variables of interest I proceed to the actual regression analysis. Estimation results in four specifications are presented in Table 6 for the *basic* and *alternative* models given by equations (1) and (4) in Section 3. First, the *simple* specification (including just the spillovers measures from trade and FDI, no control variables), *full* (all variables and all countries), *wec* (all variables but only Western European countries), *eec* (all variables for transition countries both Eastern European and Central Asian). The coefficients of the *simple* and *full* specifications are very robust through all models suggesting that previous studies (not including additional control variables in the fixed effects estimation) do not suffer from large biases. Also, the results hold for all countries and specifications when I use the Barro-Lee measure of human capital (average years of schooling among male over 25 years old) as a sensitivity check (model named *full_robust*). I report this measure only in the case of the full model and in both specifications given by equations (1) and (4) due to the space constraints. While (Eq.1) is the basic model using spillovers computed as import weighted foreign R&D stock, the alternative one (Eq.4) adds measures of inward FDI and trade openness in the formula for the respective spillovers.

The OLS estimates yield similar results with CH, LP and other studies. However, the models and country sample used are quite different so we do not expect more than this degree of similarity between the estimated coefficients. The regressions perform extremely well as a result of the cointegration relationship between the variables and the R squared is above 0.90 in all specifications and subsample suggests a very good fit.

The computed trade spillovers using CH's methodology remain positive and significant below 1 percent level throughout the models proving that foreign R&D spillovers via imports are a robust component of technology flows between countries. Moreover trade spillovers have the biggest impact on one's domestic productivity. This impact is relevant for both developed and transitional countries but the former seem to benefit even more, probably due to their trade composition that has more technological advanced countries than in the case of an Eastern European one which is less diversified. The elasticity of total factor productivity with respect to the import-weighted foreign R&D ranges between 0.13 and 0.18 in the basic model (Eq.1) and 0.06 to 0.87 in the alternative one (Eq.4)

FDI is a significant channel for international spillovers, although its impact is weaker than that of trade. Moreover, in the case of Western Europe these spillovers do not seem to have an important impact on their domestic productivity. One explanation could be founded also in the differences between FDI among developed countries and developing ones (Bloningen and Wang, 2005). Secondly, while most of the FDI is still concentrated in the industrialized countries (about 82% according to UNCTAD's statistics on FDI inflows for 2006) the developing ones are getting much less but the impact on their economies is greater[9]. Moreover, while one could expect significant differences in terms of productivity between multinational (MNCs) and domestic firms in a transitional countries, these decrease significantly in the case of developed one, giving less of an impact on the recipient's productivity. In comparison with the trade channel, the elasticity of inward FDI weighted foreign R&D is much lower between 0.001 and

[9] Although the ratio between inward FDI in Western Europe and Eastern and Central Asian transition economies is no longer in double digits, it still remains significant (19.81 in 1991, 15.85 in 2001 and 6.20 in 2006)

0.016 (Eq.1) and 0.005 and 0.013 (Eq.4). In both models, transitional countries of Eastern Europe and Central Asia seem to take enjoy larger spillovers via FDI.

As the literature predicts, the domestic stock of R&D has a significant and positive impact in all specifications. The estimated elasticities of TFP with respect to domestic R&D are between 0.003 and 0.066 (Eq.1) and 0.059 and 0.084 (Eq.4). As hypothesized in Section 3 (iii), this impact is much smaller in the sample of developing countries than otherwise. Also, in case of transitional countries the estimates are not statistically significant in both models pointing to a weaker influence of domestic R&D expenditure on productivity growth. However, even in the case of Western Europe the regressions state that technology diffusion from foreign countries via trade contributes to productivity more than the domestic efforts in research and development.

Human capital, proxied either by the Barro-Lee's average schooling years or the tertiary enrollment as a percentage of the gross, remains a very important factor for growth, consistent with (ii) hypothesis. A one percent increase in the share of tertiary enrollment yields between 0.04 and 0.08 percent increases in the country's aggregated TFP. Interestingly, but not so surprising, in the absence of significant spillovers from an outdated domestic R&D stock, human capital in Eastern has a greater impact than Western Europe. This is also a confirmation of their high quality educational systems and high share of labor force with higher education.

Although the OLS estimator of a cointegrated equation is super consistent (converges faster to its true value than when stationary), its distribution is generally not standard, especially in small samples, due to possible endogeneity of regressors and serial correlation in the residual error term[10]. As a result, the standard errors tend to be underestimated resulting in misleading statistical inferences about the coefficients. In the case of exogeneity and serial correlation violations, cointegrated relationships can be efficiently estimated by either the fully modified OLS (FMOLS) or dynamic OLS (DOLS) to obtain asymptotically consistent estimates. In their paper, Kao and Chiang (2000) demonstrate that the OLS, FMOLS and DOLS are all asymptotically normally distributed in a cointegrated panel. However, through Monte Carlo experiments they come to the conclusion that, in general, the FMOLS estimator does not improve by much the OLS results while DOLS outperforms both of them. The DOLS estimator is obtained by extending the initial equation with lags and leads of the first differenced regressors to control for endogeneity and estimate the standard errors on the basis of a long-run serial correlation robust error covariance matrix:

$$Y_{it} = \alpha_i + \beta_i X_{it} + \sum \eta_{ij} \Delta X_{i,t+j} + v_{it} \qquad j = -l_1, l_2;$$

where l_1 represents the number of lags and l_2 the number of leads. The summation over the j's represents all the additional lags and leads included in the estimation. One lag and one lead, respectively two lags and two leads of the differenced independent variables are considered for these estimations. Table 7 presents the results of the DOLS estimation (2 and 2) while the results for (1,1) are not reported because they are almost identical. These should yield robust econometric estimates, especially considering the rather low t, equaling 17 years. The DOLS results are consistent with the OLS ones confirming that trade and FDI channels are important carriers for technology across borders. The

[10] R&D spending might also react to increases in TFP causing a reversal (Griliches 1995).

elasticities of international R&D spillovers via imports have highly statistically significant coefficients, which are even larger than those obtained from OLS estimation, between 0.07 and 0.255 (basic model) and 0.01 and 0.12 (alternative model). In the case of FDI weighted knowledge stocks, the estimations have similar ranges: 0.01 to 0.03 (basic) and 0.008 to 0.027 (alternative). It is important to notice is that these results confirm the fact that both channels seem to have a higher impact on domestic TFP in the case of developing countries. Secondly, in the DOLS estimation both proxies for human capital are not statistically significant. This is due to the requirements of the estimation (lags and leads of first differences) which are confronted with low variability in these variables as described in the previous section[11]. Domestic R&D stock remains an important driver for productivity: a 1 percent increase in the capital stock of research and development yielding between 0.06 and 0.12 percent increase in the levels of aggregated TFP. The share of investment in the economy and the government expenditure share of GDP still have a small negative effect but highly significant.

6. Robustness checks

Lichtenberg and van Pottelsberghe (1998) show that the CH weighting scheme is the subject of an "aggregation bias", since a merger of countries will always increase the available stock of foreign R&D. More criticisms can be added to both the CH and the LP weighting scheme by looking at the "indirect spillovers" described in the Lumenga-Neso et al. (2004) which build on Keller (1998). However, these indirect spillovers are just a reflection of the entire R&D produced in the world and one would expect that looking only at trade related spillovers and OECD countries (very integrated among each other via trade) one would find significant results. But this might not be the case for developing or transitional economies. Thus, I will perform also estimation of equations (1) and (4) using the LP specification of FDI and respectively, trade weighted R&D stocks as given by these formulas:

$$S_{it}^{FDI} = \sum_{j=1}^{m} \frac{FDI\_inw_{jit} * FRD_{jt}}{y_{jt}} \quad (7)$$

$$S_{it}^{TRADE} = \sum_{j=1}^{m} \frac{m_{jit} * FRD_{jt}}{y_{jt}} \quad (8)$$

where FDI_inw_{jit} (m_{jit}) represents the inward flow of FDI (imports) from country j to country I and y_{jt} is the aggregated output of country j. According to these weighting schemes, a country i will "receive" from country j a fraction of its output that is exported (directly invested) to i times j's R&D stock at time t. Another interpretation could be that i receives the amount of knowledge embodied in the flows of FDI and trade coming from j times its R&D intensity at time t. As expected this intensity varies a lot within the sample and over time: Western European improvement (from 0.10 in 1990 to 0.15 in

[11] For the Barro-Lee variable values are given only for 1990, 1995 and 2000 and not available for many transitional countries, while for the tertiary in the early 1990s the coverage is very weak, only after 1998 having yearly values become a constant presence.

2006), Eastern European transitional decline (0.15 to 0.06) and the Central Asian transition countries (stagnating at 0.02 over all this period).

Table 8 presents comparative descriptive statistics about the spillover variables in log form under the two specifications (CH and LP). Despite significant magnitudes due to different computational schemes the two measures exhibit a high degree of correlation both in case of FDI and imports. Table 9 presents the fixed effects estimations for equations (1) and (4) using the LP weighting scheme. The results for the estimated effects of trade and FDI spillovers are very robust and similar to the ones obtained by using the CH weighting scheme. The estimated elasticities are a bit lower in the case of the *basic model* (0.129 to 0.132 compared to 0.131 to 0.186 in Table 8) but almost identical for the *alternative* one (0.059 to 0.077 versus 0.060 to 0.087). Similar fits (R squares over 0.92) are obtained also under (8) and (9). The DOLS estimations are in the same lines with high significant coefficients and similar elasticities for the spillover variables. The results are not reported but are available upon request.

In addition to this methodological robustness check using the LP weights, I also perform various additional estimations not reported due to space constraints. As mentioned in section 4, I employ in the estimation the actual shares of capital and labor for all the countries in the sample (Table 1) collected from the literature. Secondly, I use various depreciation rates for capital and R&D stocks computations as a sensitivity analysis. I also attempt to control efficiently the influence of human capital variable by using two proxies (Barro-Lee and tertiary enrollment percentage). Finally, for possible biases arising from endogeneity and serial correlation in the error term, I use the most efficient estimator (DOLS) in the case of cointegrated relationships, in various specifications (up to 2 lags and 2 leads).

7. Conclusion

In today’s increasingly integrated global economy, productivity of a country depends on the domestic R&D efforts but also on foreign one through the process of technology diffusion. This phenomenon is especially important for developing nations, with little or no significant R&D undergoing, where the magnitude and mechanisms of such spillovers become crucial engines for growth.

Using a newly constructed panel on 47 countries from 1990 to 2006, this study investigates in premiere two of the most important channels for technology diffusion (trade and FDI) in the case of all 27 transition countries from Eastern Europe and Central Asia. Moreover, the present estimations use the most recent methodology in panel unit roots testing and estimation of cointegrated panels (DOLS). My findings confirm the fact that trade remains the main carrier of technology for both developed and developing countries, surpassing the domestic R&D efforts even in the case of the former. Foreign direct investment seems to have a significant but much smaller impact and predominantly in transition countries where the differences in productivity between domestic and foreign own firms are expected to be larger. Human capital, in both specifications, plays a crucial role in determining TFP levels, as argued by the Nelson-Phelps hypothesis. Domestic efforts and investment in R&D has a deeper effect over the Western European countries than the Eastern ones, since the latter have inherited at the beginning of the 1990s an outdated R&D stock, specialized in mature, heavy industries (mechanical, chemical) with little potential for innovation and productivity growth. Moreover, the R&D investment has decreased significantly during the transition period in most of these countries.

The policy conclusions are straightforward. Openness to both trade and FDI from developed nations that actively create technologies at the frontier is beneficial for all countries but mostly to developing (transition) economies. However, these actions need to be complemented by a skilled, educated labor force and an active domestic R&D sector in order to absorb efficiently these spillovers. While Eastern Europe still possesses some comparative advantage in the former, the latter issue represents a significant future challenge and a factor for sustained economic growth in the region.

Over the last decades the process of globalization has accelerated openness to trade and investments from abroad both in developed and developing economies worldwide. One of its many results is that the size and importance of international knowledge spillovers has become of crucial importance for developing and transitional countries in their catch-up process. The present results contribute to the existing literature by looking at former communist countries of Eastern Europe and Central Asia and quantifying the importance of the spillover channels in their case. Further improvements to this literature could consider using industry-level data for a better localization of the spillovers which tend to cluster in certain industries. Moreover, in the case of transitional countries their industrial mix has changed significantly over the 1990s from over-industrialized countries to a more balanced economy in which the service sector has grown tremendously. An interesting study could explore how these distortions and changes have affected the foreign spillovers.

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Table 1. R&D Capital Stock Data (million constant $ 2000 prices and PPPs) and actual capital shares in the GDP

	R&D Expenditure		R&D capital stock		R&D intensity		Capital share
	Availability	Avg. annual growth (%)	Initial flow	Initial stock	1990	2005	
Australia	1981-2005	6.14	2,591	12,365	0.0793	0.1173	0.591
Austria	1981-2005	5.75	1,574	7,585	0.0954	0.1685	0.470
Belgium	1983-2005	2.89	2,791	15,250	0.1161	0.1421	0.590
Canada	1981-2005	4.82	6,281	31,728	0.0987	0.1364	0.597
Cyprus	1990-2005	20.79	55	154	0.0231	0.2487	0.526
Denmark	1981-2005	5.91	1,037	4,780	0.0957	0.1688	0.378
Finland	1981-2005	7.31	981	4,339	0.1155	0.2362	0.559
France	1981-2005	2.65	19,278	109,192	0.1538	0.1641	0.403
Germany	1981-2005	2.54	29,867	168,532	0.1777	0.2008	0.380
Greece	1981-2005	8.42	223	952	0.0218	0.0454	0.583
Iceland	1981-2005	9.47	31	134	0.0617	0.1896	0.333
Ireland	1981-2005	8.49	265	1,134	0.0520	0.0790	0.784
Italy	1981-2005	2.87	8,735	48,147	0.0854	0.0918	0.477
Japan	1981-2005	3.85	46,431	247,423	0.1804	0.2332	0.698
Korea	1991-2005	8.98	8,574	35,738	0.0876	0.1602	0.762
Malta	1990-2005	16.77	14	43	0.0143	0.0677	0.531
Mexico	1993-2005	8.98	1,546	5,852	0.0113	0.0415	0.800
Netherlands	1981-2005	2.61	4,659	26,646	0.1456	0.1400	0.502
New Zealand	1981-2005	4.65	509	2,670	0.0613	0.0814	0.522
Norway	1981-2005	4.28	1,072	5,513	0.1184	0.1317	0.414
Portugal	1982-2005	1.79	303	151	0.0239	0.0580	0.551
Spain	1981-2005	7.56	1,931	8,552	0.0441	0.0751	0.543
Sweden	1981-2005	4.83	3,499	17,758	0.1985	0.2808	0.561
Switzerland	1981-2005	3.02	3,466	19,230	0.1935	0.2228	0.600
Turkey	1990-2005	10.18	1,050	4,169	0.0136	0.0340	0.779
United Kingdom	1981-2005	1.53	21,469	129,965	0.1626	0.1341	0.545
United States	1981-2005	3.62	123,164	661,597	0.1770	0.1825	0.659
Albania	1990-2005	8.01	13	58	0.0071	0.0105	0.644
Armenia	1990-2005	3.49	24	130	0.0063	0.0055	0.600
Azerbaijan	1990-2005	-3.17	166	1,399	0.0419	0.0120	0.600
Belarus	1990-2005	-3.13	1,697	11,315	0.1949	0.0372	0.600
Bosnia and Herzegovina	1990-2005	5.47	22	110	0.0066	0.0080	0.756
Bulgaria	1990-2005	-9.00	1,798	29,997	0.6026	0.0854	0.660
Croatia	1990-2005	1.32	575	3,520	0.1062	0.0926	0.723
Czech Republic	1990-2005	-2.11	3,690	28,637	0.3123	0.1340	0.595
Estonia	1990-2005	13.70	29	102	0.0060	0.0281	0.438
Georgia	1990-2005	1.63	66	395	0.0096	0.0114	0.600
Hungary	1990-2005	-0.33	2,008	13,689	0.2043	0.0970	0.635
Kazakhstan	1990-2005	2.54	259	1,478	0.0121	0.0099	0.600
Kyrgyz Republic	1990-2005	-1.21	24	174	0.0110	0.0086	0.600
Latvia	1990-2005	1.30	106	653	0.0247	0.0216	0.666
Lithuania	1990-2005	2.80	286	1,608	0.0502	0.0454	0.600
Macedonia, FYR	1990-2005	-0.48	41	285	0.0385	0.0341	0.466
Moldova	1990-2005	-3.66	127	1,120	0.0413	0.0328	0.842
Poland	1990-2005	-3.10	4,559	38,314	0.1966	0.0570	0.665
Romania	1990-2005	-2.24	1,146	9,141	0.1139	0.0562	0.622
Russian Federation	1990-2005	-1.96	35,486	272,193	0.2365	0.1032	0.685
Serbia and Montenegro	1990-2005	-3.37	500	4,303	0.0839	0.0430	0.600
Slovak Republic	1990-2005	-4.85	1,015	10,008	0.2450	0.0625	0.565
Slovenia	1990-2005	0.78	645	4,087	0.1890	0.1161	0.511
Tajikistan	1990-2005	0.64	89	571	0.0359	0.0385	0.600
Turkmenistan	1990-2005	4.64	138	700	0.0526	0.0695	0.600
Ukraine	1990-2005	-5.91	9,226	101,573	0.3265	0.1256	0.492
Uzbekistan	1990-2005	4.86	257	1,292	0.0148	0.0175	0.600

Table 2. Summary statistics

Variable	Description	Obs	Summary Statistics			
			Mean	St.Dev	Min	Max
$\log A_{i,t}$	Log Total Factor Productivity	816	1.816	0.533	-0.020	2.719
$\log S_{it}^{TRADE}$	Log Trade Spillovers	748	8.498	2.204	0.819	12.460
$\log S_{it}^{FDI}$	Log FDI spillovers	547	8.279	2.915	-1.814	13.396
$\log DRD_{jt}$	Log Domestic R&D	791	8.359	2.222	3.751	12.712
logtertiary	Log Tertiary enrollment	663	2.144	0.206	1.373	2.473
logschool	Log avg. years school	663	2.144	0.207	1.374	2.473
ki	Investment share of GDP	816	17.329	7.812	0.380	51.522
gov	Government share of GDP	727	24.641	8.634	8.120	78.640
$\log S'_{it}{}^{TRADE}$	Alternatative FDI spillovers	739	14.398	2.346	4.608	18.938
$\log S'_{it}{}^{FDI}$	Alternatative Trade Spillovers	529	11.436	3.639	-6.454	20.112

Table 3. Panel Unit Root tests (annual data, 1990-2006)

Variable	with individual intercept and trend				with individual intercept			
	Levin, Lin and Chu	Breitung	Im, Pesaran and Shin	Hadri *	Levin, Lin and Chu	Breitung	Im, Pesaran and Shin	Hadri *
$\log A_{i,t}$	20.32 (1.00)	-1.97 (0.02)	-0.63 (0.26)	16.10 (0.00)	7.54 (1.00)		3.72 (0.99)	8.45 (0.00)
$\log S_{it}^{TRADE}$	17.95 (1.00)	1.33 (0.90)	-0.83 (0.20)	11.24 (0.00)	2.00 (0.97)		3.91 (.100)	16.27 (0.00)
$\log S_{it}^{FDI}$	18.01 (1.00)	7.20 (1.00)	1.46 (0.92)	9.68 (0.00)	-6.57 (0.00)		-0.26 (0.39)	8.99 (0.00)
$\log DRD_{jt}$	10.64 (1.00)	4.60 (1.00)	0.38 (0.65)	16.01 (0.00)	-2.56 (0.00)		0.67 (0.74)	16.79 (0.00)
logtertiary	6.79 (1.00)	-4.01 (0.00)	0.79 (0.78)	9.17 (0.00)	-8.32 (0.00)		0.49 (0.68)	14.93 (0.00)
logschool	2.67 (0.99)	-9.21 (0.00)	0.60 (0.72)	10.47 (0.00)	0.00 (0.00)		0.00 (0.00)	13.20 (0.00)
ki	0.73 (0.76)	-0.95 (0.16)	-4.03 (0.00)	11.75 (0.00)	-2.99 (0.00)		-3.65 (0.00)	13.46(0.00)
gov	-12.65 (0.00)	-1.15 (0.12)	-3.44 (0.00)	14.42 (0.00)	-14.00 (0.00)		-3.52 (0.00)	10.49 (0.00)
$\log S'_{it}{}^{TRADE}$	38.91 (1.00)	10.13 (1.00)	-0.76 (0.22)	12.76 (0.00)	16.02 (1.00)		4.09 (1.00)	15.36 (0.00)
$\log S'_{it}{}^{FDI}$	-0.96 (0.16)	2.64 (0.99)	-0.23 (0.40)	14.24 (0.00)	6.97(1.00)		1.99 (0.97)	12.86 (0.00)

In the tests' specification 4 lags were considered.
Numbers in parentheses are p-values. All tests include individual effects and individual linear trends.
* Hadri is the only test which has stationarity as the null hypothesis all the others having non-stationarity. Hadri allows also for heteroskedastic error terms

Table 4. Correlation matrix

Variables	log $A_{i,t}$	log S_{it}^{TRADE}	log S_{it}^{FDI}	log DRD_{jt}	logtertiary	logschool	ki	gov	log S'_{it}^{TRADE}	log S'_{it}^{FDI}
log $A_{i,t}$	1.000									
log S_{it}^{TRADE}	0.649	1.000								
log S_{it}^{FDI}	0.440	0.848	1.000							
log DRD_{jt}	0.344	0.857	0.752	1.000						
logtertiary	0.440	0.441	0.373	0.469	1.000					
logschool	-0.212	-0.050	0.086	0.166	0.340	1.000				
ki	0.282	0.476	0.403	0.321	0.167	-0.039	1.000			
gov	-0.466	-0.667	-0.494	-0.478	-0.214	0.080	-0.512	1.000		
log S'_{it}^{TRADE}	0.669	0.941	0.837	0.744	0.430	0.003	0.457	-0.631	1.000	
log S'_{it}^{FDI}	0.445	0.696	0.898	0.550	0.355	0.144	0.352	-0.364	0.787	1.000

Table 5. Panel cointegration tests

Model	basic			alternative		
	full	wec	eec	full	wec	eec
Pedroni tests						
Panel v-Statistic	-1.78*	-2.25**	-3.41***	-1.68*	-2.45**	-2.91***
Panel rho-Statistic	8.10***	6.07***	5.75***	9.02***	6.62***	6.32***
Panel PP-Statistic	-5.01***	-1.46	-9.30***	-6.04***	-3.30***	-7.56***
Panel ADF-Statistic	-3.37***	-1.39	-3.71***	-3.93***	-2.91***	-3.51***
Group rho-Statistic	10.95***	8.17***	7.29***	11.83***	8.61***	8.11***
Group PP-Statistic	-13.27***	-4.03***	-15.03***	-13.63***	-6.23***	-13.24***
Group ADF-Statistic	-5.30***	-1.24	-6.40***	-5.67***	-3.30***	-4.75***
Kao tests						
DF (rho)	5.66***	-11.44***	5.93***	5.71***	-10.00***	5.99***
DF* (rho)	4.90***	-11.14***	5.04***	4.97***	-9.83***	5.17***
DF (t)	-4.57***	-13.56***	3.06***	-3.34***	-13.83***	3.69***
DF* (t)	-5.48***	-13.50***	1.49*	-4.32***	-13.79***	2.19**

The null hypothesis for both tests is no cointegration; *, ** and *** indicate parameters that are significant at the 10%, 5% and respectively 1%; The lag selection is automatic based on Schwarz information criterion; the tests use a Newey-West bandwidth selection with Bartlett kernel

Table 6. Estimation results (OLS fixed effects)

	BASIC - Equation (1)					ALTERNATIVE - Equation (4)				
	simple	full	wec	eec	full_robust	simple	full	wec	eec	full_robust
log S_{it}^{TRADE}	0.146***	0.140***	0.186***	0.131***	0.159***					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
log S_{it}^{FDI}	0.016***	0.012***	0.001	0.015**	0.012***					
	(0.002)	(0.004)	(0.708)	(0.013)	(0.003)					
log DRD_{jt}		0.055***	0.066***	0.003	0.043**		0.060***	0.084***	0.062	0.059***
		(0.003)	(0.000)	(0.506)	(0.023)		(0.000)	(0.000)	(0.186)	(0.001)
logtertiary		0.066***	0.047***	0.066*			0.072***	0.040**	0.086**	
		(0.007)	(0.005)	(0.051)			(0.001)	(0.013)	(0.013)	
logschool					0.463***					0.258*
					(0.004)					(0.094)
ki		-0.002	-0.009***	-0.001	-0.006***		-0.000	-0.006***	0.001	-0.003*
		(0.159)	(0.000)	(0.660)	(0.000)		(0.947)	(0.007)	(0.568)	(0.094)
gov		-0.014***	-0.009*	-0.014***	-0.012***		-0.014***	-0.004	-0.014***	-0.012***
		(0.000)	(0.086)	(0.000)	(0.000)		(0.000)	(0.426)	(0.000)	(0.001)
log S'^{TRADE}_{it}						0.070***	0.064***	0.086***	0.060***	0.087***
						(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log S'^{FDI}_{it}						0.012***	0.011***	0.005*	0.013***	0.011***
						(0.000)	(0.000)	(0.063)	(0.000)	(0.000)
R squared	0.9531	0.9684	0.9177	0.9432	0.9684	0.951	0.9677	0.9175	0.9429	0.9667
N	535	514	278	236	468	523	502	268	234	457

The dependent variable is logarithm total factor productivity; *, ** and *** indicate parameters that are significant at the 10%, 5% and respectively 1%; P values are reported in parenthesis below the coefficients; All estimated models contain unreported fixed effects and use White standard errors and covariance (degrees of freedom corrected) for estimation

Table 7. Estimation results (DOLS Fixed Effects)

	BASIC - Equation (1)					ALTERNATIVE - Equation (4)				
	simple	full	wec	eec	full_robust	simple	full	wec	eec	full_robust
log S_{it}^{TRADE}	0.219***	0.255***	0.074***	0.391***	0.254***					
	(0.000)	(0.000)	(0.008)	(0.000)	(0.000)					
log S_{it}^{FDI}	0.038***	0.029***	0.017***	0.023	0.031***					
	(0.000)	(0.000)	(0.000)	(0.107)	(0.000)					
log DRD_{jt}		0.066***	0.086***	0.104***	0.063***		0.074***	0.109***	0.125***	0.009***
		(0.000)	(0.000)	(0.000)	(0.000)		(0.000)	(0.000)	(0.000)	(0.000)
logtertiary		0.002	0.021**	-0.078			0.031	-0.016	-0.038	
		(0.889)	(0.048)	(0.170)			(0.177)	(0.396)	(0.451)	
logschool					-0.058					-0.316*
					(0.667)					(0.086)
ki		-0.018***	-0.015***	-0.019***	-0.021***		-0.015***	-0.007***	-0.018***	-0.015***
		(0.000)	(0.000)	(0.000)	(0.000)		(0.000)	(0.001)	(0.000)	(0.000)
gov		-0.016***	-0.031***	-0.008	-0.013***		-0.019***	-0.030***	-0.018*	-0.014***
		(0.001)	(0.000)	(0.326)	(0.001)		(0.000)	(0.000)	(0.059)	(0.001)
log S'^{TRADE}_{it}						0.126***	0.109***	0.018	0.180***	0.118***
						(0.000)	(0.000)	(0.139)	(0.001)	(0.000)
log S'^{FDI}_{it}						0.022***	0.020***	0.008**	0.027***	0.023***
						(0.000)	(0.000)	(0.032)	(0.000)	(0.000)
R squared	0.9889	0.9959	0.9945	0.9935	0.9963	0.9900	0.9955	0.9959	0.9934	0.9958
N	310	296	173	123	282	286	272	151	121	260

The dependent variable is logarithm total factor productivity; Two lags and two leads were considered in this estimation; *, ** and *** indicate parameters that are significant at the 10%, 5% and respectively 1%; P values are reported in parenthesis below the coefficients; All estimated models contain unreported fixed effects and use White standard errors and covariance (degrees of freedom corrected) for estimation

Table 8. Descriptive statistics: CH and LP weights for international R&D spillovers

Variable		Obs	Mean	Std. Dev.	Min	Max	Correlation
log(fdi spillovers)	CH weights	547	8.28	2.92	-1.81	13.40	0.88
	LP weights	546	5.39	3.52	-5.63	13.10	
log(trade spillovers)	CH weights	748	8.50	2.20	0.82	12.46	0.99
	LP weights	748	7.11	2.34	-1.14	11.42	

Table 9. Robustness check: Estimation results with LP weights (OLS Fixed Effects)

	BASIC - Equation (1)					ALTERNATIVE - Equation (4)				
	simple	full	wec	eec	full_robust	simple	full	wec	eec	full_robust
log S_{it}^{TRADE}	0.130***	0.129***	0.139***	0.129***	0.132***					
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)					
log S_{it}^{FDI}	0.009**	0.008***	0.006***	0.008*	0.010***					
	(0.016)	(0.003)	(0.007)	(0.056)	(0.002)					
log DRD_{jt}		0.053***	0.057***	0.063	0.041**		0.051***	0.076***	0.058	0.059***
		(0.000)	(0.000)	(0.506)	(0.013)		(0.001)	(0.000)	(0.203)	(0.001)
logtertiary		0.040	0.026	0.053*			0.071***	0.034	0.088***	
		(0.141)	(0.298)	(0.080)			(0.001)	(0.209)	(0.009)	
logschool					0.247					0.165***
					(0.119)					(0.009)
ki		-0.001	-0.008***	0.000	-0.000**		-0.000	-0.006***	0.002	-0.003
		(0.560)	(0.000)	(0.993)	(0.027)		(0.777)	(0.000)	(0.418)	(0.418)
gov		-0.013***	-0.008	-0.014***	-0.011***		-0.012***	-0.004	-0.013***	-0.011***
		(0.001)	(0.192)	(0.000)	(0.001)		(0.001)	-0.485	(0.003)	(0.003)
log S'^{TRADE}_{it}						0.062*	0.059***	0.067***	0.058***	0.077***
						(0.057)	(0.005)	(0.000)	(0.010)	(0.010)
log S'^{FDI}_{it}						0.010***	0.008***	0.005***	0.009**	0.009**
						(0.010)	(0.009)	(0.007)	(0.011)	(0.011)
R squared	0.9587	0.9698	0.9202	0.9443	0.9703	0.9703	0.9688	0.9191	0.9436	0.9684
N	536	520	282	238	472	519	504	271	233	460

The dependent variable is logarithm total factor productivity; *, ** and *** indicate parameters that are significant at the 10%, 5% and respectively 1%; P values are reported in parenthesis below the coefficients; All estimated models contain unreported fixed effects and use White standard errors and covariance (degrees of freedom corrected) for estimation

Appendix A. Data: construction, sources

The Appendix A provides additional details on the construction of variables, assumptions and data sources.

List of countries

- *OECD countries* used in this study are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States of America.
- *Eastern European* transitional countries (EECs): Albania, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russian Federation, Serbia and Montenegro, Slovakia, Slovenia, Ukraine.
- *Central Asian* transitional countries (CACs): Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.
- *Western European* countries (WECs): Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom.

Perpetual Inventory Method (PIM)

To convert flow figures into stock variables I use the perpetual inventory method. Assuming that the relationship between the steady state stock variable S* and its flow value F* is given by:

$$(1+g)^{t+1} S^* = (1-\zeta)(1-g)^t S^* + (1+g)^t F^*, \qquad t = 0,\ldots, T$$

where g is the average annual growth and ζ (zeta) is a time invariant depreciation suitable for the variable in case. By rearranging (1) one can solve for S* as $S^* = F^* / (\zeta+g)$, while the subsequent stock data are given by $S_t = (1-\zeta) S_{t-1} + F_{t-1}$.

Total Factor Productivity

Data on total GDP (in millions of 1990 PPP US$) and employment (thousands) comes from the Groningen Growth and Development Centre and the Conference Board, Total Economy Database. The physical capital stock values are computed using data on aggregate investment share as a percentage of GDP from the World Table Version 6.2 (1990-2004). Some of the values of these aggregated investment shares have been linearly extrapolated to cover the last years. For computations of the capital stock in year t, I use once again the PIM. The initial stock is computed using the method developed by Griliches (1979): $KS_0 = I_0 / (g + \delta)$ where I_0 is the investment at the beginning of the period, g is the average growth rate for the 17 years of available data and δ is the depreciation rate, set at 10 percent, most commonly used rate in the literature. The subsequent stocks are computed as $KS_t = (1-\delta) KS_{t-1} + I_t$, where I_t equals the investment flow in the current year

R&D capital stocks

Domestic R&D stocks are computed using the GERD figures available from OECD's Main Science and Technology Indicators 2007. The very few missing values are interpolated taking into account the evolution of national gross domestic product as the main factor driving the gross expenditure on research and development. Again, PIM is applied also for computation of the R&D stocks. The initial stock is computed for the first available year (1980) and the subsequent yearly depreciation rate is fixed at 15 percent ($\xi = 0.15$). This rate is higher than the one applied to capital stocks on the premise that economic life cycle of technology is much shorter than the one of capital (Lee, 2006). The initial value, $RDS_{1980} = RD_{1980} / (g + \xi)$ where g is computed as the average growth rate of gross R&D expenditures over the period 1980 to 2006. In the case of non-OECD countries, I use the indicator GERD as a percentage of GDP (from UNESCO Statistical Yearbooks, supplemented by Eurostat and national statistics) and values for total GDP in constant 2000 $ PPP (World Development Indicators 2007 – the World Bank) to derive the yearly flows of GERD while the stocks are computed using PIM and the same depreciation rate. Overall, the advantage of this approach resides in the compatibility of the stocks in both the case of Western/OECD and Eastern European countries, results being reported in Table 1. However, there are some caveats which are detailed next. For Bosnia Herzegovina since there were no reported data on GERD, I assume the same share for it over GDP as in a similar country (population, structure and common institutional legacy) of another former Yugoslav Republic, Macedonia. Also, I assume that the percentage of GDP dedicated to R&D activities is similar in Tajikistan, Turkmenistan and Uzbekistan, while Moldova's case I consider the only available data (percentage of GERD in GDP) not to vary over time and compute the annual GERD flows using this value. For Albania, the indicators are taken from an official presentation of Agolli E.(Ministry of Education and Science) and Bushati S.(Albanian Academy of Science) at the UNESCO Workshop on "Science, Technology and Innovation Indicators: Trends and Challenges in South-Eastern Europe" held in Skopje, Macedonia between 27 and 31 March 2007.

Trade related spillovers

Data on bilateral trade in US $ for all countries between 1990 and 2006 is coming from IMF's Direction of Trade Statistics (DOTS) 2007. Prior to 1997, trade data for Belgium are recorded as trade of the Belgium-Luxembourg Economic Union (BLEU) in which Luxembourg counts for about 3 to 4 percent of the total. About 8 percent of the values are missing since, all in the EEC and CAC cases since most of these countries have become separate entities only in 1991 (former Soviet Union and Yugoslavia) or 1993 (Czech Republic and Slovakia). DOTS data exclude adjustments for unrecorded trade (including shuttle trade) and, prior to 1994 exclude trade with the countries of the former U.S.S.R.
The trade shares with OECD countries are computed as percentage of imports of country j from country i over the total exports of i to the world.

Openness to trade

It is constructed as an index of imports over GDP. The data for imports and exports to and from the world is extracted from DOTS 2007. The flows are reconstructed for 1990 and 1991 in the case of countries that have broken up that year (USSR, Yugoslavia) and

1993 for Czechoslovakia, using their aggregate statistics and their relative shares in the first year of independence. GDP data in current US $ comes from World Development Indicators 2007.

Bilateral FDI data

The OECD International Direct Investment Statistics Yearbook is the most important source of data for bilateral flows among OECD countries and most studies use it with some contingent assumptions. However, the data coverage is not very good even among Western European states and this aspect becomes critical when analyzing the Eastern European and Central Asian ones. As a consequence, I rely mainly on the UNCTAD World Investment Directory which contains country profiles with detailed FDI data both inward and outward. Using this source I compute the FDI spillovers for each country using the formula (2) and respectively (5) for the alternative model. I allow for positive spillovers in country i from country j even when the total outflows of country j to the world are negative. Thus, $s_{jit}^{FDI} = FDI_{it} / ABS (\sum FDI_{jt})$ if $FDI_{it}>0$, otherwise $s_{jit}^{FDI} = 0$ (zero spillovers due to disinvestment.). In the case of Canada, due to the aggregation of the flow data, I use stock data to recalculate the flows and percentages corresponding to each country in which Canadian firms have invested over the period 1990 to 2005.

Human Capital

Is measured by the average years of school attainment of the total population aged 25 and over in a country. Data comes from Barro and Lee (2000) and has a 5 year frequency. For the former Yugoslav republics that are not covered with individual data we use the same values provided under the name "Yugoslavia" since their educational system and structure must have been similar at least until the mid 1990s. The same is applied for the European CIS states Belarus, Russia and Ukraine due to their similarities.

The second measure for Human Capital comes from World Development Indicators 2007 and is the school tertiary enrollment as a percentage of the gross. Although this indicator has a yearly frequency, the coverage is complete only between 1998/1999 and 2004/2005 for most countries in the sample. Its main advantage besides a higher variance in the observations relies in the fact that, unlike the Barro-Lee data, all cross-sections are represented.

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