International R&D spillovers in emerging markets: the impact of trade and foreign direct investment

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Abstract

While economic theory predicts that growth in developing countries will gain significantly from technology spillovers, the empirical evidence on this issue remains relatively scarce. The present study focuses on a panel of 27 transition and 20 developed countries between 1990 and 2006 and uses the latest developments in panel unit root and cointegration techniques to disentangle the effects of international spillovers via inflows of trade and FDI on total factor productivity (TFP). The findings show that imports remain the main channel of diffusion for both sets of countries, while FDI, although statistically significant, has a lower impact on productivity of the recipients. The domestic R&D capital stock plays an active role in Western Europe while in the Eastern part it is less significant due to lower levels, transitional disinvestment and relative obsolescence. Human capital affects TFP directly as a factor of production as well as indirectly by enhancing a country's absorptive capacity. In aggregate, the results show that transition countries from Eastern Europe and Central Asia seem to enjoy bigger productivity gains from the international diffusion process than their Western counterparts.

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

1 Introduction

Over the last decade studies by Hall and Jones (1999) and Easterly and Levine (2001) have shown 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 industrialized countries account for most of the world's new technology creation, the developing ones rely mainly on technological spillovers from abroad (Keller, 2004; Saggi, 2002, Eaton and Kortum, 1999)[1]. 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 and Wang, 2000; Van Pottelsberghe de la Potterie and Lichtenberg, 2001). However, despite the growing importance of these inflows for the developing world, there are only few studies that focus on foreign R&D spillovers in these countries.

This study attempts to fill this gap and contributes to the literature as follows. First, it analyzes in premiere the process of technological diffusion in transition countries. Although a small number of studies have included developing nations in their sample, most of the former communist countries from Eastern Europe and Central Asia remain to this date uncovered[2]. Moreover, unlike previous studies, their domestic R&D stock is computed and included in the estimations as a control variable. Secondly, it employs two possible channels of diffusion, namely inward FDI and imports. 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 in the analysis. Thirdly, the study provides comparisons between the richer Western Europe and its poorer Eastern neighbors in order disentangle the efficiency of these channels and the differences in this process. Furthermore, pooling together developed and developing nations may yield ambiguous results, while the effects of FDI or trade may be very different (Bloningen and Wang, 2005). Fourthly, the choice of weighting schemes for these flows is recognized as a crucial aspect in the spillovers literature. Here I use a different weighting scheme that seems more straightforward and robust, accommodating the criticisms of previous measures. Finally, in order to avoid spurious regressions, I employ panel cointegration and dynamic OLS estimation to obtain the long run relationship between total factor productivity and R&D spillovers.

The present study finds that both trade and FDI are important channels for diffusion of technologies across countries. However, a robust result, consistent with previous work (Crispolti and Marconi, 2005; Ciruelos and Wang, 2005) is that trade has a stronger effect than FDI for both developing and developed nations. Controlling for the effect of own domestic R&D efforts, I find that for transition countries this is weaker, reflecting the transitional disinvestment and outdated technological specialization of the region, as a negative legacy from the communist period (Krammer, 2009). There are also signs of strong heterogeneity among countries in terms of the effects of foreign R&D. Human capital determines directly productivity levels and also contributes to the successful absorption of new knowledge from

[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).

[2] There are several papers (Damijan et al., 2003; Javorcik, 2004; Chinkov, 2006) that have dealt with a number of "advanced" transition countries from Central Europe like Czech Republic, Hungary or the Baltic states; however, the majority of the 27 transition countries have not been explored yet.

abroad. The government expenditure is negatively correlated with technical efficiency, while the overall investment rate in a country does not seem to play a role in determining it.

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 and transitional countries. As a result, economic growth depends more and more on a country's portfolio of trade and investment partners. While for world's innovative leaders the spillovers of technology may yield both positive and negative incentives for R&D investment, developing countries are expected to gain in terms of welfare in all scenarios. By engaging in economic activities with foreign partners, and under certain conditions, countries can access foreign sources of knowledge at a lower cost than that incurred when producing it themselves.

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 fifth reports the econometric analysis and results. Section six provides additional robustness check tests while section seven offers conclusions.

2 Literature review

The topic of technological spillovers has been widely explored in the recent economic literature at different levels of analysis. While there are still debates with respect to specifications, measurements and methodological issues, the bulk of studies seem to agree on a couple of key issues.

In the following I am going to enunciate some of these stylized facts focusing on the macro level, while their validity could extend beyond it. First, both developing and developed 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 a handful of industries from few industrialized countries. Thus, any productivity increases due to technological advancements outside these selected areas draws significantly upon these spillovers. 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). As a result, we observe significant differences among countries in terms of spillovers they receive[3]. Finally, most empirical research, despite different levels of data aggregation and techniques of analysis, confirms the existence and importance of these spillovers.

This section provides a comprehensive overview of the theoretical and empirical developments in these strains of literature.

2.1 Trade

Trade can help the diffusion of technology in a number of ways: it opens up the channels of communication for transmission of technical information, reduces duplication of research internationally and enhances competition and through enlargement of available markets (Grossman and Helpman, 1991). The three types of factors that influence the process of

[3] One of these aspects, heavily documented in the literature, is the geographical localization of spillovers.

technological transfer among countries through trade can be summarized as: the effort to transfer these technologies, the absorptive capacity of the recipient country, and the differences between it and the donor in terms of distance to the world's frontier (Hoppe, 2005).

There are a handful of theoretical models of technological diffusion that constitute the backbone of the recent empirical literature. Grossman and Helpman (1991) stress 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. Further looking into the gains from trade, Devereux and Lapham (1994) model the transitional dynamics associated with trade liberalization. They show that, although the implications may differ for developed versus developing countries, trade is beneficial to economic growth even in the absence of knowledge flows. Despite the continuous sophistication of these models, gaps still exist between their well behaved conclusions and some empirical findings in the literature, which are subject to measurement and data availability constraints.

The empirical work at the macro level is large and quite diverse. It focuses mostly on developed countries and considers various specifications for the 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 (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 "truly" random trade shares[4]. 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 results are quite similar to those 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 again some doubts on the validity of CH's results. However, 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, both the CH and LP analyses focus 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

[4]They claim that Keller's random weights are just simple averages with a random error and that when using alternative random weights the spillovers are not existent, as expected.

stock even if 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 their argument for "indirect" spillovers .

Further refinements 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 (Xu and Wang, 1999). This result is confirmed by subsequent work using imports of machinery goods to measure trade spillovers (Eaton and Kortum, 2001; Xu and Chiang, 2005). The most recent trends explore the role of international spillovers while controlling for domestic R&D and intra- and inter-industry spillovers (Schiff et al., 2003; Acharya and Keller, 2007).

2.2 Foreign Direct Investment

FDI has always been considered an important channel for technological diffusion on the basis that multinationals transfer technology between different subsidiaries. Besides the usual benefits associated with FDI, in terms of jobs and higher wages, the possibility for technological spillovers gives more reasons to compete in attracting FDI, and also adds an important policy dimension to this issue.

However, early studies using micro data have founded negative or no effects of FDI on domestic productivity in developing countries (Aitken and Harrison, 1999; Konings, 2000; Gorg and Greenaway, 2003). Among possible explanations for this they list: (i) a strong 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 such small positive effects. Oppositely, 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 imports and outward foreign investment as significant channels, but surprisingly not the incoming FDI[5]. Damijan et. al (2003) analyze a panel of 8,000 firms for ten Eastern European countries over the period 1995 to 1999 and conclude that FDI effects are significant in five of these ten countries and give more importance to the vertical spillovers. Crispolti and Marconi (2005) find technological spillovers from US, Japanese and European FDI in 45 developing countries from Asia, Latin America and Africa between 1980 and 2000. Finally, Ciruelos and Wang (2005) look at a sample of 47 OECD and developing countries from 1988 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.

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

2.3 Other channels

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 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 framework

The empirical specification follows the "expanding variety" endogenous growth models. 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:

$$A(t) = N(t)^{\gamma}, \text{ with } \dot{N}(t) = \eta RD(t) \tag{3.1}$$

where $A(t)$ is the technological efficiency, $N(t)$ is the number of intermediate goods, $RD(t)$ is the total R&D effort to develop new products, while η and γ are strictly positive parameters. Hence 3.1 implies that productivity growth is a linear function of the R&D efforts of a country[6]:

$$\frac{\dot{A}}{A} = \psi RD(t) \text{ where } \psi = \eta\gamma \tag{3.2}$$

The final output is produced using a variety of intermediate inputs produced by both domestic and foreign firms, hence the technical efficiency depends not only on domestic R&D efforts but foreign ones (RD_f) as well:

$$\frac{\dot{A}_i}{Ai} = \psi^d RD_i(t) + \psi_1^f RD_{j1}(t) + \psi_2^f RD_{j2}(t) + ... + \psi_n^f RD_{jn}(t) \tag{3.3}$$

where n represents the number of foreign countries (j) that provide intermediate goods to country i. Spillovers occur through transfer of intermediate goods via two channels, namely imports and foreign direct investment from any j to country i. This bears the assumption that FDI and trade to be rather complements than substitutes. However, most empirical studies support complementarity, which makes our assumption legitimate[7]. Besides trade in intermediate goods, foreign firms that come into country i are assumed to be technologically advanced and able to produce new varieties of intermediate goods at a lower cost. Hence, the technical efficiency of a country i has the following form:

[6] This implies also scale effects i.e. productivity growth proportional to population growth; to neutralize these one can use instead the R&D intensity (R&D over GDP).

[7] For a recent empirical exploration of this issue in the case of Central and Eastern Europe see Filippaios and Kottaridi (2008) and for good survey Forte (2004).

$$\frac{\dot{A}_i}{Ai} = \psi^d RD_i(t) + S_i^{TRADE} + S_i^{FDI} \tag{3.4}$$

where the spillovers depend on the amount of R&D intensity undertaken by the donor country and the strength of the respective flows: $s_{ji}^{FDI} = f(RD_{jt}, FDI_{jit})$ and $s_{ji}^{TRADE} = f(RD_{jt}, M_{jit})$. $FDIji(t)$ represents the inflows of FDI while $Mji(t)$ are the total value of imports, both from j to i in time t. In order to compute the size of these spillovers, I assume that the total amount of R&D that gets transferred from j to i is j's knowledge (R&D) stock times the intensity of the carrying flow relative to the donor country:

$$S_{it}^{TRADE} = \sum_{j \neq i} s_{jit}^{TRADE} RD_{jt} \tag{3.5}$$

$$S_{it}^{FDI} = \sum_{j \neq i} s_{jit}^{FDI} RD_{jt} \tag{3.6}$$

with $i = 1, m; j = 1, n; i \neq j$. s_{jit}^{TRADE} (s_{jit}^{FDI}) represent the share of imports (inward FDI) of country i originated from country j in year t as a percentage of the total exports (outward FDI) of country j in that year. RD_{jt} represents the stock of R&D of country j in the same year t. Hence, S_{it}^{TRADE} (S_{it}^{FDI}) is the trade (FDI) weighted foreign R&D stock that accounts for the technological spillovers through inward imports (FDI). The weights employed here are similar to Ciruelos and Wang (2005) and differ in several ways from previous ones used in the literature[8]. For the empirical estimation I employ a log-linear specification for 3.4 (*basic model*) to assess the impact of these spillovers on the domestic total factor productivity of a host country i:

$$\log A_{it} = \alpha_i + \beta_1 \log S_{it}^{TRADE} + \beta_2 \log S_{it}^{FDI} + \beta_3 \log X_{it} + \epsilon_{it} \tag{3.7}$$

where $\log A_{it}$ is the logarithm of total factor productivity (TFP) in country i (recipient), α_i represents a country-specific constant term while the vector of control variables (X_{it}) include measures of domestic R&D stock (RD_{jt}), human capital (HK_{jt}) and government expenditure (GOV_{jt}). All these variables that are presented in the literature as major influences on TFP and ultimately, economic growth. Consistent with the literature on absorptive capacity, a certain level of *human capital* is needed for technological catching up (Nelson and Phelps, 1966; Benhabib and Spiegel, 1994), while a high skilled labor force can impacts productivity also directly (Engelbrecht, 2002). Countries differ also in terms of *investment rates* which may enhance or prohibit also the inward flows of FDI and trade[9]. Although the effects and causality of *government expenditure* on growth are still a subject of debate in the literature there seems to be a strong relationship between the two (Barro, 1990; Easterly and Rebelo, 1993; Gupta et al., 2005).

Subscribing to CH's argument that countries that are more open to the inflows of goods (and FDI in our case) will benefit more from foreign spillovers, I employ an *alternative model* that accounts for this openness:

[8] CH weights use the sum of total inflows to i while LP weights the GDP of j as the denominator.

[9] 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. The mean investment share of GDP in Central and Eastern Europe is 15.43 percent, between Central Asia (10.68%) and the developed West (21.56%).

$$\log A_{it} = \alpha_i + \beta_1 \log S_{it}^{\prime TRADE} + \beta_2 \log S_{it}^{\prime FDI} + \beta_3 \log X_{it} + \epsilon_{it} \tag{3.8}$$

$$S_{it}^{\prime TRADE} = \left(\frac{\sum_{j \neq i} M_{ijt}}{Y_{it}} \right) \sum_{j \neq i} s_{jit}^{TRADE} RD_{jt} \tag{3.9}$$

$$S_{it}^{\prime FDI} = \left(\frac{\sum_{j \neq i} FDI_{ijt}}{Y_{it}} \right) \sum_{j \neq i} s_{jit}^{FDI} RD_{jt} \tag{3.10}$$

where M_{jit} are the total value of imports of country i to the world, Y_{it} is the total output and FDI_{ijt} is the total inward FDI to i, all in year t[10]. The vector of control variables (X_{it}) remains the same.

4 Data description

This paper employs a panel of 47 countries over the period 1990 to 2006. About half of them (20) are developed Western European while the rest are transition countries: 19 from Central and Eastern Europe and 8 from Central Asia. The starting year of our analysis coincides with the beginning of the transition process from a centralized economy towards a free market one. As the source for technology spillovers, I use data on 25 OECD countries that account for the majority of the world's R&D investment. Further details on the data, definition of variables and sources are provided in `Appendix 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[11]. In addition, as a robustness check I use the actual shares of capital and labor income collected from the literature and reported in the last column of Table 1. These shares come quite close to our assumptions (0.80 correlation coefficient) and using this robust measure of TFP yields very similar results. 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 constructed using data on aggregate investment share as a percentage of GDP from the World Table Version 6.2 using the perpetual inventory method.

[10] Since we do not want to capture the effects of overall trade (FDI) intensity for a country, we use only inward flows. Both exports and especially outward FDI are really low for transition countries.

[11] I 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: ΔY = 0.33 ΔK + 0.59 ΔL, with both coefficients highly significant ($p<0.000$) and a high R squared (0.88).

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 investment flows using GERD (UNESCO Statistical Yearbooks, Eurostat and national statistics offices) and GDP data (World Development Indicators 2007). To compute these stocks I employ again the perpetual inventory method.

4.3 Foreign R&D stocks embodied in imports

The R&D spillovers from OECD25 are computed following equations 3.5 for the basic model and 3.9 for the alternative one that emphasizes openness to trade. Bilateral trade flows are taken from IMF's Direction of Trade 2007 (DOTS). 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 3.6 and respectively 3.10. Detailed inward FDI flows are procured from individual statistics for these 25 OECD countries as reported in the annexes of the UNCTAD World Investment Report 2007. Using this data source gives some advantage in terms of time series consistency and more observations for transition countries than the OECD International Direct Investment Statistics.

4.5 Human capital measures

As a proxy for the human capital available in a country I use two measures. The first comes from the widely employed Barro and Lee (1996) dataset and its updated 2000 version. This index covers also some Eastern European countries and reports the *average years of secondary schooling* in male population over 25 years old over five-year periods. The data confirms the high quality of human capital available in transition 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 for human capital is the *tertiary enrollment* as a percent of the gross. Yearly values come from World Development Indicators 2007: Western Europe has a tertiary enrollment rate of 43 percent, while Eastern Europe (37%) and Central Asian (26%) countries are quite close. Finally, due to the better coverage of the latter, 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 between 1990 and 2004 are taken from World Penn Tables 6.2. These shares are obtained by dividing each of these components to the real

GDP. The data confirms “Wagner’s law”, according to which governmental 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

5.1 Estimation issues, unit root and cointegration

Table 2 presents the descriptive statistics for the variables employed in this study[12]. The first concern is *multicollinearity* which could be a major obstacle in estimation of international technological spillovers when including multiple channels (Griliches, 1979). Similar to others (Lee, 2006) the correlation matrix (Table 3) exhibits one high pair wise correlation (0.85) that could affect the statistical significance of our estimates. However, it neither exceeds the critical tolerance level implied by the literature (0.90), nor blow up the standard errors of the estimates, entitling me to conclude that multicollinearity is not an issue in this case. In order to stay away from such problems, I also avoid using excessive control variables.

Before proceeding to the actual estimations, one needs to investigate the time series properties of these variables in order to avoid a spurious regression, since it is well known that some of them present a *unit root*. I opt for panel unit root and cointegration tests that have higher power than those based on individual time series, especially when the latter are not very long. While some assume a cross-sectional common unit root (Breitung, 2000; Hadri, 2000; Levin, Lin and Chu, 2002) others allow for individual processes across sections (Im, Pesaran and Shin, 2003). The outcomes of these tests, presented in Table 2, show clearly 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 find out if there is a cointegration relationship between these variables. For this I employ the tests proposed by Pedroni (1999). These residual-based tests have all the null hypothesis of no cointegration and also allow for heterogeneous cross sectional variance. Pedroni (2004) conducts various Monte Carlo experiments to assess the power of these tests and concludes that in very small panels the group rho statistics is the most conservative one, while for fairly large panels the v-statistic provides the best power. In between these two extremes, his results suggest that the parametric *group-t statistic* and *panel-t statistic* appear to have the highest power, followed by the *panel-rho statistic*. These values and their significance levels are reported in Tables 4 and 5 for each regression. Overall, one can reject most of the times the null of no cointegration, giving legitimacy to our estimations.

5.2 Basic results and discussion

Given that there is a cointegrating relationship between the variables of interest, I proceed with the actual regression analysis. Estimation results in four specifications are presented in Table 4 for the *basic* and *alternative* models given by equations 3.7 and 3.8. First, the

[12] All variables are in logarithmic form and the coefficients can be interpreted as elasticities, except the percentage variables (tertiary enrollment, investment rate and government expenditure) for which such interpretation would not make much sense.

simple specification (including just the spillovers measures from trade and FDI, no control variables), *full* (all variables and all countries), *wec* (only Western European countries) and *trc* (only transition countries). The coefficients of the *simple* and *full* specifications are quite robust suggesting that previous studies (employing only a fixed effects estimation but no additional controls) do not suffer from large biases. Also, the results hold for all countries and specifications when using 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*). Due to space constraints, I report this measure only in the case of the full model in both specifications.

The estimates are similar to those of CH, LP and others. However, the specifications and samples of countries used are quite different so I do not expect more than this degree of similarity between the estimated coefficients. Overall, the regressions perform well and the R squared values are relatively high for panel estimations.

The computed trade spillovers remain positive and highly significant at 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 present for both developed and transitional countries but the former seem to benefit even more, probably due to their trade composition differences between West and East. The elasticity of total factor productivity with respect to the import-weighted foreign R&D ranges between 0.134 and 0.177 in the basic model, and 0.061 to 0.088 in the alternative one.

FDI also serves as a channel for international spillovers, although its impact is weaker than that of trade. Moreover, in the case of Western Europe these spillovers seem to have a very low impact on their domestic productivity. One explanation could be founded also in the structural 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 for the ones that receive it the impact is obvious. Moreover, while one could expect significant differences in terms of productivity between multinational (MNCs) and domestic firms in 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 0.000 and 0.017 (basic), and 0.005 and 0.015 (alternative). In both models, transitional countries of Eastern Europe and Central Asia seem to enjoy larger spillovers via FDI than their Western counterparts.

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 0.031 and 0.073 (basic) and 0.069 and 0.084 (alternative). As hypothesized in Section 3 (iii), this impact is usually smaller for developing countries than otherwise. Also, in case of transitional countries the estimates are not statistically significant in the basic model and only significant at 10% in the alternative one, pointing to a weaker influence of domestic R&D expenditure on productivity growth. This is consistent with some predictions for the less developed countries (Devereux and Lapham, 1994) and previous findings on Eastern Europe (Chinkov, 2006; Krammer, 2009). Moreover, even in the case of Western Europe, regressions confirm that foreign technology diffusion 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 factor for growth. A ten percent increase in the share of tertiary enrollment yields between 0.02 and 0.01 percent increases in the country's aggregated TFP. When using another proxy (the Barro Lee variable) in a log form, a 10 percent increase of the average schooling level gives between 2.6 and 4.6 percent increase in productivity. 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, both in the basic and alternative models and for both proxies[13]. This confirms their high quality educational systems and important share of labor force with higher education.

5.3 Estimation of cointegrated relationships

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 . 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) that provide asymptotically consistent estimates. However, using Monte Carlo experiments, Kao and Chiang (2000) show that DOLS outperforms FMOLS. This 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:

$$y_{it} = \alpha_i + \beta_i x_{it} + \sum_{k=-l1}^{l2} \eta_{ij} \Delta x_{it-k} + v_{it} \tag{5.1}$$

where l1 represents the number of lags and l2 the number of leads. Table 5 presents the results of the DOLS estimation (2 lags and 2 leads) while the results for the (1,1) specification are very similar. Moreover, the DOLS results confirm that trade and FDI channels are important carriers for technology across borders. The elasticities of international R&D spillovers via imports have highly statistically significant coefficients, which are even larger than those obtained from fixed effects estimation, between 0.080 and 0.311 (basic) and 0.020 and 0.127 (alternative model). In the case of FDI weighted knowledge stocks, the estimated coefficients have similar ranges: 0.016 to 0.038 (basic) and 0.009 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 in most cases not statistically significant. This is due to the requirements of the estimation (lags and leads of

[13] These regressions are not reported here. The elasticity of average secondary schooling in transition countries is 1.22 (basic) and 1.40 (alternative) versus 0.24 and respectively, 0.08, for Western European states.

first differenced regressors) confronted with low variability of these variables for most of the 1990s that generates higher standard errors. Domestic R&D stock remains an important driver for productivity: a 1 percent increase in the capital stock of research and development yields between 0.061 and 0.119 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 but highly significant negative effect.

6 Robustness checks

In this section I have explored the validity of the results in several ways: employing a different weighting scheme (LP) for computing the spillovers; running a sensitivity analysis with various lags and leads for the DOLS specification; looking at the impact of relative backwardness on productivity; and analyzing interactions that can be interpreted as evidence of the absorptive capacity hypothesis. In addition, I perform additional estimations using the actual shares of capital and labor collected from the literature (Table 1), and explore various depreciation rates for capital and R&D stocks. In all cases, the main findings of the paper remain valid.

6.1 Weighting scheme

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. Thus, would like to check my preferred weights (CW) against this possible bias (see `Appendix B`). Hence, I will re-estimate equations 3.7 and 3.8 using the LP specification, as given by these formulas:

$$S_{it}^{TRADE} = \sum_{j=1}^{n} \frac{M_{jit}}{Y_{jt}} * RD_{jt} \tag{6.1}$$

$$S_{it}^{FDI} = \sum_{j=1}^{n} \frac{FDI_{jit}}{Y_{jt}} * RD_{jt} \tag{6.2}$$

According to this weighting scheme, 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. Here, the interpretation is that the more R&D intensive j is the more knowledge will spill over to i, embodied in the flows of FDI and trade from j. As expected, this intensity varies a lot within the sample and over time: Western European increase (from 0.10 in 1990 to 0.15 in 2006), Eastern European transitional decline (0.15 to 0.06) and the Central Asian constant low performance (stagnating around 0.02).

Despite significantly different magnitudes the two spillover measures exhibit a high degree of correlation both in case of FDI and imports (see Table 6). Table 7 presents the fixed effects estimations using the LP weighting scheme. The results for the estimated effects of trade and FDI spillovers are very robust and similar to the previous findings. The estimated elasticities are a bit lower in the case of the basic model (0.126 to 0.136 compared to 0.134 to

0.177 in Table 4) but almost identical for the alternative one (0.063 to 0.077 versus 0.061 to 0.088) showing that both weighting schemes generate similar results and conclusions. The corespondent 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.

6.2 DOLS specification

To address 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. However, in practice it is difficult to choose the optimal DOLS structure. While the role of leads is related to the concept of Granger causality, sometimes they are unnecessary (Hayakawa and Kurozumi, 2006). For the purpose of this paper, I only report the DOLS (2,2) results that considers two lags and two leads of the first differenced regressors to derive the long run relationship between them and TFP. However, I perform additional regressions using a DOLS (2,1) and DOLS (1,1) specification and the results are robust.

6.3 Relative backwardness and absorptive capacity

Often, the literature argues that relative backwardness (the distance from world's technological frontier) and absorptive capacity (the capacity to adopt foreign technologies) stand out as two major drivers of the catching-up process (Gerschenkron, 1962; Nelson and Phelps, 1966). In order to explore this hypothesis, I include in my estimations interaction factors between proxies for this domestic capacity, namely human capital (HK) and domestic R&D efforts (DRD), and a measure of backwardness (GAP). Our aim is to control for these two factors and see if trade and FDI spillovers still have a significant impact on TFP. The GAP variable is computed relative to the most advanced economy in the world (USA) in per capita terms, as follows:

$$GAP_{j,t} = \frac{GDPPC_{USA,t} - GDPPC_{j,t}}{GDPPC_{USA,t}} \tag{6.3}$$

The interactions between GAP and HK and DRD account for the role of education and domestic R&D in the absorption of disembodied knowledge spillovers (Benhabib and Spiegel, 1994). The results (Table 8) are in lines with previous findings. GAP is negative and statistically significant showing that the more backward a country is, the lower its productivity (i). When interacting $tertiary$ with GAP, the coefficient is positive and statistically significant showing that higher education in relatively backward countries is inducing productivity enhancements (ii). However, the coefficient on education is insignificant consistent with other studies (Falvey et al., 2007). Similar findings are presented in case of domestic R&D, which again, is enhancing productivity both directly as a factor of production, and indirectly, by increasing the absorptive capacity of a country (iii). Next, we present several interactions between human capital and domestic R&D, and spillovers via trade and FDI, but the effects are rather small and not statistically significant. Since these interaction variables are highly correlated (0.92 and 0.95) with the original spillovers, their negative sign and increased standards errors point out towards multicollinearity issues that prevent us from drawing valid inferences. In conclusion, both human capital and domestic R&D efforts increase the absorptive capacity of a country and contribute to productivity increases; moreover, the coefficients for our variables of interest, foreign spillovers from trade and FDI, remain robust throughout these regressions, showing that they haven't been overstated in previous specifications.

7 Conclusion

In today's increasingly integrated global economy, productivity of a country depends not only on the domestic R&D efforts, but on foreign ones as well, via spillovers of technological content across borders. This phenomenon is especially important for developing nations, with little or no significant R&D undergoing, where the magnitude of such spillovers becomes a crucial engine for growth.

Using a newly constructed panel of 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, and compares them with mature economies from Western Europe. Moreover, the present analysis uses the most recent methodology in panel unit root testing and estimation of cointegrated panels. My findings confirm that trade remains an important source for productivity increases via technological spillovers for both developed and developing countries[14]. Consistent with previous findings, the importance of these effects surpasses their national R&D efforts, clearly in the case of transition countries, and to some extent even the developed ones. This proves the massive impact of international trade flows on productivity and economic growth worldwide. Foreign direct investment has a significant but much smaller impact, predominantly in transition countries where the differences in productivity between domestic and foreign-owned firms are larger. Human capital impacts significantly the level of TFP of a country both directly, as a factor of production, and indirectly, as the main determinant of its absorptive capacity along. the domestic R&D efforts. These have larger effects in Western Europe than in the East, probably due to the fact that the latter have inherited from their communist decades an outdated technological portfolio focused on mature, heavy industries with little potential for innovation and productivity growth in the present. Moreover, in most of these countries, the R&D investment has decreased continuously throughout the 1990s, further affecting their capacity to develop and harness their existing R&D capabilities.

The policy conclusions are straightforward. Openness to both trade and FDI from developed nations that actively create technologies is beneficial for all countries. Trade seems to yield somewhat higher benefits for developed countries which enjoy also a dense trade network and exchange high volumes among themselves. However, these benefits are balanced by a higher impact of FDI driven spillovers in developing (transition) economies. On average, considering both types of spillovers throughout our models and estimations, transition countries seem to gain more than their Western counterparts, confirming the relative backwardness advantage. However, in order to efficiently absorb these spillovers, they need to maintain an highly educated labor force and develop an active domestic R&D sector. While transition countries still possess some comparative advantage in the former, the latter

[14] The only exception is the DOLS (2,2) estimation of the alternative model in the case of Western European countries.

represents a significant challenge for the future, and a requirement 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 a vital engine for developing and transitional countries catching-up process. The present results contribute to the existing literature by looking at 27 former communist economies and quantifying the importance of the spillover channels in the case of these countries from Eastern Europe and Central Asia. Further improvements to this could consider using sector 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. Another interesting line of research could explore the size and dynamics of indirect spillovers effects via FDI and see if the results hold and improve in any way the present estimations.

A Appendix. Data: construction and sources

A.1 Sample 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.
- Transition countries (TRC) from Eastern Europe: 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.
- Transition countries (TRC) from Central Asia: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.
- Western European countries (WEC): Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom. Due to their treatment in the official statistics prior to 1995, Belgium and Luxembourg are aggregated into one entity called BLEU, the Belgium-Luxembourg Economic Union.

A.2 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). For computations of the capital stock in year t, I use the perpetual inventory method (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 $KS_t = (1 - \delta)KS_{t-1}$, where I_t equals the investment flow in the current year

A.3 R&D capital stocks

Domestic R&D stocks are computed again using PIM and the gross expenditure on R&D (GERD) figures from OECD's Main Science and Technology Indicators 2007. The initial stock is computed for the first available year (1980) and the subsequent yearly depreciation rate is fixed at 15 percent (ξ= 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. 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 (see Table 1). 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 Macedonia, another former Yugoslav Republic. 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) to be constant 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.

A.4 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. About 8 percent of the values are missing since, all for the transition countries since most of them became 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. Openness to trade 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.

A.5 FDI related spillovers

Here I rely mainly on the UNCTAD World Investment Directory which contains country profiles with detailed FDI data both inward and outward. 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, $s_{jit} = \frac{FDI_{it}}{ABS(\sum FDI_{jt})}$ if $FDI_{it} > 0$ and $s_{jit} = 0$ (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.

B Appendix. Weighting scheme

In this appendix I am going to explore the robustness of my chosen weights (CW) to the LP critique of the original CH weights, which suffer from an "aggregation bias" in case of a merger between two countries. For this purpose, I am going to look at the impact of a merger between two OECD "donor" countries (France and Germany) on the amount of R&D spillovers received by Poland and Czech Republic and analyze how different weights (CW, CH, LP) perform under this scenario.

Table B1. The sensitivity of R&D spillovers from trade in the case of a merger

Countries	*Czech Republic*			*Poland*		
Weighting scheme	**CH**	**LP**	**CW**	**CH**	**LP**	**CW**
Before the merger	110,778	2,875	8,782	93,438	3,211	10,554
After the merger	192,993	2,682	9,104	165,386	3,107	10,861
Difference	74.22%	-3.70%	3.67%	77.00%	-3.24%	2.91%

The merger increases substantially the amount of spillovers in the recipient countries when using the CH weights while the LP and CW ones prove to be a lot more robust to such issue.

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Table 1. R&D statistics (average growth, flows, stocks, intensity) and actual capital shares (β)

Country	Period	Growth (%)	Initial flow	Initial stock	Intensity 1990	Intensity 2005	β
Australia	1981-2005	6.14	2,591	12,365	0.08	0.12	0.59
Austria	1981-2005	5.75	1,574	7,585	0.10	0.17	0.47
Belgium	1983-2005	2.89	2,791	15,250	0.12	0.14	0.59
Canada	1981-2005	4.82	6,281	31,728	0.10	0.14	0.60
Cyprus	1990-2005	20.79	55	154	0.02	0.25	0.53
Denmark	1981-2005	5.91	1,037	4,780	0.10	0.17	0.38
Finland	1981-2005	7.31	981	4,339	0.12	0.24	0.56
France	1981-2005	2.65	19,278	109,192	0.15	0.16	0.40
Germany	1981-2005	2.54	29,867	168,532	0.18	0.20	0.38
Greece	1981-2005	8.42	223	952	0.02	0.05	0.58
Iceland	1981-2005	9.47	31	134	0.06	0.19	0.33
Ireland	1981-2005	8.49	265	1,134	0.05	0.08	0.78
Italy	1981-2005	2.87	8,735	48,147	0.09	0.09	0.48
Japan	1981-2005	3.85	46,431	247,423	0.18	0.23	0.70
Korea	1991-2005	8.98	8,574	35,738	0.09	0.16	0.76
Malta	1990-2005	16.77	14	43	0.01	0.07	0.53
Mexico	1993-2005	8.98	1,546	5,852	0.01	0.04	0.80
Netherlands	1981-2005	2.61	4,659	26,646	0.15	0.14	0.50
New Zealand	1981-2005	4.65	509	2,670	0.06	0.08	0.52
Norway	1981-2005	4.28	1,072	5,513	0.12	0.13	0.41
Portugal	1982-2005	1.79	303	151	0.02	0.06	0.55
Spain	1981-2005	7.56	1,931	8,552	0.04	0.08	0.54
Sweden	1981-2005	4.83	3,499	17,758	0.20	0.28	0.56
Switzerland	1981-2005	3.02	3,466	19,230	0.19	0.22	0.60
Turkey	1990-2005	10.18	1,050	4,169	0.01	0.03	0.78
United Kingdom	1981-2005	1.53	21,469	129,965	0.16	0.13	0.55
United States	1981-2005	3.62	123,164	661,597	0.18	0.18	0.66
Albania	1990-2005	8.01	13	58	0.01	0.01	0.64
Armenia	1990-2005	3.49	24	130	0.01	0.01	0.60
Azerbaijan	1990-2005	-3.17	166	1,399	0.04	0.01	0.60
Belarus	1990-2005	-3.13	1,697	11,315	0.19	0.04	0.60
Bosnia and Herzegovina	1990-2005	5.47	22	110	0.01	0.01	0.76
Bulgaria	1990-2005	-9.00	1,798	29,997	0.60	0.09	0.66
Croatia	1990-2005	1.32	575	3,520	0.11	0.09	0.72
Czech Republic	1990-2005	-2.11	3,690	28,637	0.31	0.13	0.60
Estonia	1990-2005	13.70	29	102	0.01	0.03	0.44
Georgia	1990-2005	1.63	66	395	0.01	0.01	0.60
Hungary	1990-2005	-0.33	2,008	13,689	0.20	0.10	0.64
Kazakhstan	1990-2005	2.54	259	1,478	0.01	0.01	0.60
Kyrgyz Republic	1990-2005	-1.21	24	174	0.01	0.01	0.60
Latvia	1990-2005	1.30	106	653	0.02	0.02	0.67
Lithuania	1990-2005	2.80	286	1,608	0.05	0.05	0.60
Macedonia, FYR	1990-2005	-0.48	41	285	0.04	0.03	0.47
Moldova	1990-2005	-3.66	127	1,120	0.04	0.03	0.84
Poland	1990-2005	-3.10	4,559	38,314	0.20	0.06	0.67
Romania	1990-2005	-2.24	1,146	9,141	0.11	0.06	0.62
Russian Federation	1990-2005	-1.96	35,486	272,193	0.24	0.10	0.69
Serbia and Montenegro	1990-2005	-3.37	500	4,303	0.08	0.04	0.60
Slovak Republic	1990-2005	-4.85	1,015	10,008	0.24	0.06	0.57
Slovenia	1990-2005	0.78	645	4,087	0.19	0.12	0.51
Tajikistan	1990-2005	0.64	89	571	0.04	0.04	0.60
Turkmenistan	1990-2005	4.64	138	700	0.05	0.07	0.60
Ukraine	1990-2005	-5.91	9,226	101,573	0.33	0.13	0.49
Uzbekistan	1990-2005	4.86	257	1,292	0.01	0.02	0.60

Note: Flows and stocks are in million constant $ 2000 prices and PPPs, while R&D intensity is GERD over GDP;
Source: Own calculations based on OECD MSTI 2007, national statistics

Table 2. Summary statistics and panel unit root tests

		Summary Statistics					Panel Unit Root Tests			
Variable	Description	Obs	Mean	St.Dev	Min	Max	LLC	B	IPS	H
$\log A_{it}$	Log TFP	816	1.82	0.53	-0.02	2.72	20.32	-1.97*	-0.63	16.10***
$\log S_{it}^{TRADE}$	Log Trade Spillovers	748	8.50	2.20	0.82	12.46	17.95	1.33*	-0.83	11.24***
$\log S_{it}^{FDI}$	Log FDI spillovers	547	8.28	2.92	-1.81	13.40	18.01	7.20	1.46	9.68***
$\log DRD_{jt}$	Log Domestic R&D	791	8.36	2.22	3.75	12.71	10.64	4.60	0.38	16.01***
$tertiary$	Tertiary enrollment (% gross)	782	38.14	17.57	7	90	3.38	0.89	0.40	11.43***
$\log school$	Log avg. years school	663	2.14	0.21	1.37	2.47	2.67	-9.21***	0.60	10.47***
ki	Investment (% GDP)	816	17.33	7.81	0.38	51.52	0.73	-0.95	-4.03***	11.75***
gov	Government (% GDP)	727	24.64	8.63	8.12	78.64	-12.65	-1.15	-3.44***	14.42***
$\log S_{it}^{\prime FDI}$	Alternative FDI spill.	739	14.40	2.35	4.61	18.94	38.91	10.13	-0.76	12.76***
$\log S_{it}^{\prime TRADE}$	Alternative Trade spill.	529	11.44	3.64	-6.45	20.11	-0.96	2.64	-0.23	14.24***

Note: The unit root tests considered 4 lags and include individual effects and individual linear trends. Hadri (H) is the only test which has stationarity as the null hypothesis and allows for heteroskedastic error terms.

Table 3. Correlation matrix

Variables	$\log A_{it}$	$\log S_{it}^{TRADE}$	$\log S_{it}^{FDI}$	$\log DRD_{jt}$	$tertiary$	$\log school$	ki	gov	$\log S_{it}^{\prime FDI}$	$\log S_{it}^{\prime TRADE}$
$\log A_{it}$	1.00									
$\log S_{it}^{TRADE}$	0.65	1.00								
$\log S_{it}^{FDI}$	0.44	0.85	1.00							
$\log DRD_{jt}$	0.34	0.86	0.75	1.00						
$tertiary$	0.41	0.41	0.33	0.43	1.00					
$\log school$	-0.21	-0.05	0.09	0.17	0.34	1.00				
ki	0.28	0.48	0.40	0.32	0.22	-0.04	1.00			
gov	-0.47	-0.67	-0.49	-0.48	-0.23	0.08	-0.51	1.00		
$\log S_{it}^{\prime TRADE}$	0.67	0.94	0.84	0.74	0.40	0.00	0.46	-0.63	1.00	
$\log S_{it}^{\prime FDI}$	0.45	0.70	0.90	0.55	0.32	0.14	0.35	-0.36	0.79	1.00

Table 4. Fixed effects estimation (dependent variable log TFP)

	BASIC model					ALTERNATIVE model				
	simple	full	wec	trc	full_robust	simple	full	wec	trc	full_robust
log S_{it}^{TRADE}	0.147***	0.148***	0.177***	0.134***	0.160***					
	(0.013)	(0.013)	(0.036)	(0.019)	(0.012)					
log S_{it}^{FDI}	0.016***	0.014***	0.000	0.017***	0.012***					
	(0.004)	(0.004)	(0.004)	(0.006)	(0.004)					
log DRD_{jt}		0.061***	0.073***	0.031	0.043***		0.067***	0.089***	0.060*	0.060***
		(0.014)	(0.015)	(0.033)	(0.013)		(0.014)	(0.014)	(0.035)	(0.014)
$tertiary$		0.001**	0.001***	0.001			0.001**	0.001**	0.002**	
		(0.001)	(0.000)	(0.001)			(0.020)	(0.000)	(0.031)	
log $school$					0.463***					0.259*
					(0.123)					(0.136)
ki		-0.003*	-0.009***	-0.001	-0.007***		-0.000	-0.007***	0.002	-0.004**
		(0.001)	(0.002)	(0.002)	(0.001)		(0.001)	(0.002)	(0.002)	(0.002)
gov		-0.014***	-0.008**	-0.015***	-0.013***		-0.014***	-0.003	-0.015***	-0.013***
		(0.001)	(0.003)	(0.003)	(0.002)		(0.001)	(0.003)	(0.003)	(0.002)
log $S_{it}^{\prime TRADE}$						0.070***	0.068***	0.086***	0.061***	0.088***
						(0.009)	(0.009)	(0.019)	(0.013)	(0.009)
log $S_{it}^{\prime FDI}$						0.012***	0.012***	0.005*	0.015***	0.011***
						(0.002)	(0.002)	(0.003)	(0.004)	(0.002)
Pedroni tests										
Panel rho-stat	6.97***	8.10***	6.07***	5.75***	1.58***	6.02***	9.02***	6.62***	6.32***	9.75***
Panel t-stat	-2.54	-5.01***	-1.46	-9.30***	14.14***	-6.84	-6.04***	-3.30***	-7.56***	-12.39***
Group t-stat	-0.45	-13.27***	-4.03***	-15.03***	-20.06***	-0.02	-13.63***	-6.23***	-13.24***	-28.27***
R squared	0.29	0.48	0.59	0.46	0.50	0.24	0.44	0.57	0.44	0.46
N	535	514	278	236	476	523	502	268	234	457

Note: *, ** and *** indicate parameters that are significant at the 10%, 5% and respectively 1%; Standard errors are reported in parenthesis below the coefficients; All estimated models contain unreported fixed effects and use White standard errors; For the Pedroni tests, the null hypothesis for both tests is no cointegration; the lag selection is automatic based on Schwarz information criterion; the tests use a Newey-West bandwidth selection with Bartlett kernel. "wec" refers to Western Europe while "trc" to transition countries.

Table 5. Dynamic OLS estimation (dependent variable log TFP)

	BASIC model					ALTERNATIVE model				
	simple	full	wec	trc	full_robust	simple	full	wec	trc	full_robust
log S_{it}^{TRADE}	0.219***	0.245***	0.080**	0.311***	0.255***					
	(0.026)	(0.031)	(0.038)	(0.084)	(0.027)					
log S_{it}^{FDI}	0.038***	0.029***	0.016**	0.029**	0.031***					
	(0.009)	(0.007)	(0.007)	(0.015)	(0.007)					
log DRD_{jt}		0.061***	0.082***	0.096*	0.064***		0.068***	0.102***	0.119**	0.091***
		(0.017)	(0.018)	(0.052)	(0.015)		(0.021)	(0.018)	(0.055)	(0.019)
$tertiary$		0.001	0.001	-0.001			0.001*	0.000	0.001	
		(0.001)	(0.000)	(0.002)			(0.001)	(0.001)	(0.002)	
log $school$					-0.058					-0.317
					(0.156)					(0.196)
ki		-0.019***	-0.015***	-0.018***	-0.021***		-0.015***	-0.007***	-0.018***	-0.016***
		(0.002)	(0.002)	(0.004)	(0.002)		(0.002)	(0.001)	(0.004)	(0.002)
gov		-0.015***	-0.029***	-0.006	-0.014***		-0.019***	-0.030***	-0.012	-0.015***
		(0.003)	(0.004)	(0.007)	(0.003)		(0.004)	(0.003)	(0007)	(0.003)
log $S_{it}^{\prime TRADE}$						0.127***	0.109***	0.020	0.141***	0.119***
						(0.017)	(0.021)	(0.017)	(0.046)	(0.020)
log $S_{it}^{\prime FDI}$						0.022***	0.020***	0.009**	0.027***	0.023***
						(0.005)	(0.005)	(0.004)	(0.008)	(0.004)
R squared	0.54	0.81	0.91	0.82	0.83	0.57	0.77	0.92	0.82	0.79
N	310	296	173	123	282	286	272	151	121	260

Note: This estimation includes two lags and two leads of first differenced regressors; All estimated models contain unreported fixed effects and use White standard errors

Table 6. Comparison CW versus LP weights

Variable		Obs	Mean	Std. Dev.	Min	Max	Correlation
log S_{it}^{TRADE}	CW weights	748	8.50	2.20	0.82	12.46	0.99
	LP weights	748	7.11	2.34	-1.14	11.42	
log S_{it}^{FDI}	CW weights	547	8.28	2.92	-1.81	13.40	0.88
	LP weights	546	5.39	3.52	-5.63	13.10	

Table 7. Robustness check – Fixed Effects estimation with LP weights (dependent variable log TFP)

	BASIC model					ALTERNATIVE model				
	simple	full	wec	trc	full_robust	simple	full	wec	trc	full_robust
log S_{it}^{TRADE}	0.126***	0.131***	0.136***	0.127***	0.133***					
	(0.010)	(0.011)	(0.027)	(0.015)	(0.010)					
log S_{it}^{FDI}	0.011***	0.011***	0.006*	0.011*	0.011***					
	(0.003)	(0.003)	(0.003)	(0.005)	(0.003)					
log DRD_{jt}		0.058***	0.062***	0.047	0.041***		0.063***	0.081***	0.057	0.053***
		(0.013)	(0.016)	(0.035)	(0.013)		(0.014)	(0.014)	(0.038)	(0.013)
tertiary		0.000	0.000	0.000			0.000*	0.000**	0.001	
		(0.000)	(0.000)	(0.001)			(0.001)	(0.000)	(0.001)	
log *school*					0.247**					0.165
					(0.125)					(0.134)
ki		-0.000	-0.008***	0.001	-0.006***		0.001	-0.007***	0.002	-0.003**
		(0.001)	(0.001)	(0.002)	(0.001)		(0.001)	(0.001)	(0.418)	(0.001)
gov		-0.012***	-0.008**	-0.012***	-0.011***		-0.013***	-0.003	-0.013***	-0.011***
		(0.002)	(0.003)	(0.002)	(0.001)		(0.002)	(0.003)	(0.003)	(0.002)
log $S_{it}^{\prime TRADE}$						0.063***	0.065***	0.066***	0.063***	0.077***
						(0.008)	(0.008)	(0.016)	(0.012)	(0.008)
log $S_{it}^{\prime FDI}$						0.010***	0.009***	0.005**	0.011***	0.009***
						(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Pedroni tests										
Panel rho-stat	2.48**	13.76***	6.49***	8.89***	7.29***	6.64***	9.76***	6.19***	7.10***	7.52***
Panel t-stat	-9.34***	-8.26***	-6.37***	-5.79***	-1.84***	-7.33***	-3.78***	-2.56**	-5.61***	8.69***
Group t-stat	2.27**	-19.68***	9.28***	-17.92***	-11.34***	-0.46	-20.72***	-12.00***	-17.72***	-20.31***
R squared	0.34	0.50	0.60	0.49	0.52	0.26	0.45	0.58	0.45	0.47
N	533	517	282	235	472	519	504	271	233	460

Note:All estimated models contain unreported fixed effects and use White standard errors; For the Pedroni tests, the null hypothesis for both tests is no cointegration; the lag selection is automatic based on Schwarz information criterion; the tests use a Newey-West bandwidth selection with Bartlett kernel.

Table 8. Exploring the relative backwardness and absorptive capacity hypotheses

	BASIC model - CW weights						
	i	ii	iii	iv	v	vi	vii
log S_{it}^{TRADE}	0.141***	0.132***	0.138***	0.152***	0.148***	0.143***	0.147***
	(0.013)	(0.014)	(0.013)	(0.014)	(0.014)	(0.038)	(0.013)
log S_{it}^{FDI}	0.013***	0.013***	0.013***	0.013***	0.017***	0.014***	0.030**
	(0.004)	(0.004)	(0.003)	(0.003)	(0.005)	(0.003)	(0.0.14)
log DRD_{jt}	0.051***	0.058***	-0.058	0.061***	0.061***	0.056	0.073***
	(0.014)	(0.015)	(0.038)	(0.014)	(0.014)	(0.041)	(0.017)
$tertiary$	0.001**	-0.000	0.002***	0.003	0.002*	0.001**	0.001***
	(0.000)	(0.000)	(0.001)	(0.002)	(0.001)	(0.000)	(0.000)
ki	-0.003**	-0.004***	-0.004***	-0.002**	-0.003**	-0.003*	-0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
gov	-0.014***	-0.014***	-0.013***	-0.015***	-0.015***	-0.015***	-0.015***
	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
GAP	-0.358**	-0.541***	-1.821***				
	(0.142)	(0.156)	(0.488)				
$tertiary * GAP$		0.005***					
		(0.001)					
log $DRD_{jt} * GAP$			0.167***				
			(0.053)				
$tertiary *$ log S_{it}^{TRADE}				-0.000			
				(0.000)			
$tertiary *$ log S_{it}^{FDI}					-0.000		
					(0.000)		
log $DRD_{jt} *$ log S_{it}^{TRADE}						0.001	
						(0.005)	
log $DRD_{jt} *$ log S_{it}^{FDI}							-0.002
							(0.002)
R squared	0.48	0.49	0.49	0.48	0.48	0.48	0.48
N	514	514	514	514	514	514	514

Note:All estimated models contain unreported fixed effects and use White standard errors;