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by

Muhammad Ali
Uwe Cantner
Ipsita Roy

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Knowledge Spillovers through FDI and Trade: Moderating Role of Quality-Adjusted Human Capital

Muhammad Ali[1], Uwe Cantner and Ipsita Roy

Abstract

The paper extends the findings of Coe and Helpman (1995) model of R&D spillovers by considering foreign direct investment (FDI) as a channel for knowledge spillovers in addition to imports. Deeper insights on the issue are provided by examining inter-relationship between knowledge spillovers from imports and inward FDI. Moreover, human capital is added to the discussion as one of the appropriability conditions for knowledge spillovers. However, in comparison to most studies that rely on physical, monetary or indicator-based measures of human capital, the current study proposes a quality-based indicator of human capital that allows for better comparison of human capital stock across countries. Quality adjusted human capital is derived by weighting human capital data based on average years of schooling using journal publications in science and technology and patent applications. Using cointegration estimation method on 20 European countries from 1995 to 2010, the direct effects of FDI-related as well as import-related spillovers on domestic productivity are confirmed. Furthermore, a strong complementary relationship is found between knowledge spillovers through the channels of imports and inward FDI implying strong joint effect on domestic productivity. When considering quality-adjusted human capital, countries with better human capital are found to benefit not only from direct productivity effects, but also from absorption and transmission of international knowledge spillovers through imports and inward FDI. Finally, technological distance with the frontier does not appear to play a role in the absorption of knowledge spillovers.

Keywords: Knowledge spillovers, foreign direct investment, international trade, human capital

JEL classification: F14, F62, I25, J24

1. Corresponding Author

1 Introduction

In the endogenous growth literature, the importance of international knowledge spillovers in explaining domestic productivity is widely acknowledged. Prior research on technological progress (Romer 1989; Aghion and Howitt 1990; Grossman and Helpman 1991; Coe and Helpman 1995; Engelbrecht 1997) proposes that a country's productivity depends not only on its own R&D efforts but also on foreign R&D which is transmitted through channels of knowledge spillovers. In identifying the mechanism for knowledge spillovers, a considerable body of theoretical and empirical literature focuses on international trade as the most important channel through which knowledge and technology are transferred across boundaries. Other recent studies claim that international trade accounts for only 20% of productivity effect from foreign R&D and subsequently propose alternate spillover channels- such as outward and inward FDI (Wang and Blomström 1992; Borensztein, De Gregorio, and Lee 1998; Glass and Saggi 1998; Xu and Wang 2000; Branstetter 2006), labor mobility and social networks (Bernard and Bradford Jensen 1999; Keller 2004), patent flows (Eaton and Kortum (1996); Eaton and Kortum 1999, Xu and Chiang 2005, geographical proximity (Keller 2004; Fischer, Scherngell, and Jansenberger 2009) and cross-licensing (Lee 2006) to explain productivity growth.

While existing research exploits different channels of knowledge spillovers and provides significant quantitative evidence with respect to each, a consensus seems to have been reached that international trade and FDI are the most effective channels through which external knowledge and foreign technologies are transferred across countries. Trade in tangible intermediate inputs, manufactured goods and capital equipment result in efficient use of domestic resources and hence raises domestic productivity. Furthermore, it enables open communication among trade partners that leads to "cross-border" learning about foreign technologies and materials, production processes and organizational routines. Outward FDI enables greater returns on domestic investments by exploiting a foreign country's competitive advantage. Inward FDI, on the other hand leads to greater access and diffusion of foreign technologies, productivity gains, forward and backward linkage effects and introduction of new skills and organizational practices in host countries. Furthermore, following from the literature on location choice and appropriability conditions relating to FDI (Feinberg and Majumdar 2001; Alcácer and Chung 2007), FDI enhances the ability of the country to absorb potential spillover-benefits related to the investment. Labor mobility of trained employees from multinational corporations (MNCs) to domestic firms increases the social capital stock of domestic firms, resulting in greater availability, absorption and implementation of foreign knowledge. This in turn raises firms' productivity and long-term performance of the domestic economy as a whole.

Evidently, the literature on international trade and inward and outward FDI as spillover channels is extensive. However, discussed so far is the individual effects of trade and FDI on domestic productivity assuming them to be two unrelated channels of spillovers. This constitutes an important drawback given the fact that trade and FDI are very much related (Brainard 1997) and therefore the complementarity or substitutability needs to be analyzed when examining their impact on productivity growth. Knowledge spillovers from trade can occur through import of intermediate inputs and high-tech merchandise and services, while that from FDI can occur through channels of backward linkages (Javorcik 2004), vertical linkages in the form of spillovers to suppliers and customers (Lall 1980), worker mobility (Blomström and Kokko 1998) and demonstration effects in the form of imitation and reverse engineering (Saggi 2006). Yet, irrespective of the nature of spillovers through trade and FDI, empirical evidence remains inconclusive regarding their exact relationship (Fontagné 1999; De Mello and Fukasaku 2000).

The relationship between knowledge spillovers in general and productivity has also received much attention from labor economists in the last few decades. Education of labor force and their accumulated stock of human capital significantly determine a country's ability to create new ideas and adapt old ones (Lucas 1988; Nelson and Phelps 1966; Borensztein, De Gregorio, and Lee 1998; Xu and Wang 2000). Apart from this direct effect of human capital stock on productivity growth, human capital also raises domestic productivity through greater absorption and diffusion of international technological spillovers and provision of suitable appropriability conditions for FDI. Existing literature in this regard suggests that an adequate level of human capital is necessary for technological spillovers to have a significant positive impact on domestic productivity. However, despite theoretical predictions, empirical findings on the exact relationship between channels of technological spillovers and the level of human capital in determining productivity growth remains inconclusive (Blomström, Kokko, and Mucchielli 2003). Various explanations for the inconsistent findings are provided in the literature, the most important being the way human capital stock is measured and compared across countries (Ramos, Suriñach, and Artís 2010). In other words, most studies explain economic growth and technological innovation in terms of variations in the quantity of domestic human capital, with little or no attention paid to the quality differences amongst countries with respect to human capital (Hanushek and Kimko 2000).

Based on the above arguments, this study provides an integrated approach to explain the exact mechanism by which spillover channels raise domestic productivity and the role of human capital therein. Specifically, it makes advances in the following directions: First, the Coe and Helpman (1995) model of R&D spillovers is extended by additionally analyzing FDI as an important channel for knowledge spillovers and the impact of trade and FDI-related knowledge spillovers on domestic productivity is investigated. In this regard, attention is restricted to knowledge spillovers via imports and inward FDI to ensure better identification of the spillover channels, as well as easy comparability with standard literature on the topic (Grossman and Helpman 1991; Benhabib and Spiegel 1994; Coe, Helpman, and Hoffmaister 1995, Coe and Helpman 1995). However, unlike existing studies that explain trade and FDI as two independent channels of spillovers, the current study considers them as strongly overlapping and analyzes their relative and combined effectiveness on productivity. Second, human capital is considered not as an ordinary input in the domestic production function, rather as a moderating variable that provides necessary conditions for absorption and transmission of trade and FDI-related knowledge spillovers and subsequent productivity growth. Accordingly, a quality-based index of human capital is proposed that allows for comprehensive and systematic comparison of human capital stock across countries. Finally, this study builds on the catching-up hypothesis that countries farther away from the technological frontier benefit more from knowledge spillovers, and compares productivity effects of knowledge spillovers between countries with large distance to technological frontier and countries with relatively smaller distance to technological frontier.

The rest of the paper is organized as follows: Section 2 gives the conceptual background on knowledge spillovers through international trade and FDI and an overview of quality-based indicator of human capital. Section 3 introduces the econometric models and section 4 discusses the data. Section 5 presents the econometric methodology considered to analyze the relevant research questions. Section 6 summarizes the main findings and section 7 discusses the results.

2 Theoretical Background

2.1 Knowledge Spillovers through International Trade and Foreign Direct Investment

Literature on the theory of endogenous technological progress presents mixed evidence on the importance and relative effectiveness of knowledge spillovers for the domestic economy. Earlier studies go back to Grossman and Helpman (1991), henceforth GH) who formulate a theoretical model of product-variety where total factor productivity of a country increases with the number of varieties of intermediate products available in the market, and the share of labor employed in their production. Furthermore, authors show that changes in the degree of openness of an economy, as measured by the level of trade promotion or trade protection, also affect long-run growth rate, transition to steady state, volume of bilateral trade and the level of social welfare. Extending GH, Coe and Helpman (1995) (henceforth CH), study the role of knowledge spillovers from foreign innovative activities through the channel of international trade. Authors argue that in addition to domestic innovative efforts measured by profit maximizing R&D investments of entrepreneurs, foreign innovative activities also affect technological progress in home country. Hence, total factor productivity is defined as a function of domestic R&D and foreign R&D. There can be direct and indirect benefits of foreign R&D to domestic economies. A direct impact arises from direct transfer of technology while indirect benefits are realized through transmission channels such as trade and foreign direct investment. In context of their paper, the extent to which these foreign R&D efforts can be transferred depends on how open the country is to international trade. Using panel cointegration technique for long-run relationship on data for OECD countries for the period 1971-1990, authors find that there is a close link between factor productivity and domestic as well as foreign R&D capital stocks. Moreover, trade is found to play an important role in transferring R&D related know-how from partners to home countries. Other empirical studies, such as Lichtenberg and Pottelsberghe de la Potterie (1998) and Kao, Chiang, and Chen (1999) reach similar conclusions for different countries.

So far, most seminal papers analyzing the relationship between international knowledge spillovers and productivity have considered trade as the most important channel for knowledge spillover. Keller 1998, contrariwise, studies the robustness of CH results using Monte-Carlo-based test and challenges the findings that international R&D spillovers are trade related. In the Monte-Carlo experiment, international R&D spillovers are studied for randomly matched trade partners and comparison is then made between true values and ones generated by simulation exercise. The findings suggest that results of CH do not change even when the trade partners are randomly matched which casts doubts on the claim that pattern of international trade is important in knowledge spillovers. It is therefore suggested that any further models should also allow simultaneously for trade-unrelated international technology diffusion. Consequently, a second strand of literature introduces FDI as an additional channel for international knowledge spillovers[2] and investigates the effect of FDI-related knowledge spillovers on domestic productivity. Hejazi and Safarian (1999) include FDI weighted R&D in the CH model in addition to import weighted R&D for G6 countries. Similar to the CH study, authors find that both foreign and domestic R&D significantly affect domestic productivity. Additionally, the coefficient for FDI weighted foreign R&D is found to be higher than the trade weighted R&D variable while the inclusion of FDI significantly reduces the significance of trade weighted foreign R&D. Moreover they find that when R&D variables are interacted with trade openness, they lose significance. Authors interpret this result as no matter to which extent the economy is open, technological spillovers do take place through FDI and trade. Branstetter (2006) studies the scope of technological spillovers through FDI by Japanese firms to US using patent citations from Japanese firms in US patent office and argues that knowledge spillovers can go in either direction: firms investing in host country brings knowledge from home country and also learn from domestic pool of knowledge in home country. Results, robust to US-Japan technological alliances, suggest that FDI not only brings information into home country but also benefits the investing firm through local stock of knowledge. Exploring further at firm level, some studies examine the spillovers through backward and forward linkages. Javorcik (2004) use panel data for Lithuanian firms and find evidence only for backward linkages and not for forward linkages. Similarly, Kugler (2006) and Bwalya (2006) find evidence for backward linkages but not for forward linkages in Colombian and Zambian manufacturing sectors, respectively. Schoors and Tol (2002), however, in addition to evidence for spillovers through backward linkages, find negative spillovers effects through forward linkages.

In recent years, both international trade and FDI have been added as spillover channels in the productivity equation. Xu and Wang (2000), for example, examine the relationship between MNC activities (outward FDI) and trade in capital goods and technology diffusion for 21 OECD countries during 1971-1990 and find contrasting results. While a significant positive impact of foreign R&D spillovers through the channels of international trade and outward FDI is found on domestic total factor productivity, no such effect is find with respect to inward FDI. Authors interpret the results in terms of methodological limitations and unavailability of quality data, while acknowledging the need to give greater attention to econometric issues. Keller (2009) proposes a theoretical framework in identifying the contribution of international trade and FDI in the economic performance of a country and finds that geographical proximity is an important condition for knowledge diffusion. Furthermore, author claims that the two channels

2. The paper differentiates between the two concepts of knowledge transfer and knowledge spillovers, as empirical studies tend to examine the effects of knowledge transfer rather than knowledge spillovers (Blalock and Gertler 2005). We explicitly define knowledge spillovers as knowledge involuntarily transmitted from one party to another (Smeets 2008).

are indeed correlated and therefore empirical studies should focus on understanding this relationship. Saggi (2002), in a detailed review of literature, suggests that growth enhancing effects of FDI are larger in countries which follow export promotion rather than import substitution strategies. This is because countries which follow more open trade regimes usually target the bigger global market as against countries which undertake import substitution, and therefore attract more FDI. Thus the trade policy regime is found to be an important determinant of the effect of FDI on the domestic economy, necessitating the need to examine how they interact when included in the productivity model together.

While theoretical predictions on the inter-relationship between international trade and FDI are significant, empirical evidence remains scarce. Filippaios and Kottaridi (2008) compare the investment development path between EU and CEEC and find a strong complementarity between inward FDI and imports in determining international investors' behavior. Fontagné (1999) in a review of literature states that, while studies in the 1980s claimed international trade to have generated FDI, in recent years the causality has been reversed. Based on these claims, one can expect that the relationship between trade and FDI varies with several micro and macro characteristics such as firm attributes and market orientation, sectoral affiliation or the country under analysis. From the perspective of the investing (home) country, outward FDI can be considered a substitute for exports because of increased production and sale of finished goods by the foreign multinational corporations (MNC) established in the host market. However, inward FDI can increase the host country's imports by acquiring raw materials and intermediate inputs necessary for production by foreign multinational corporations to be imported from the parent country. Unavailability of appropriate intermediate products, quality considerations or highly-specific production process of the foreign affiliates in the host country can trigger such a complementary relationship. The literature on gravity models Brenton, Mauro, and Lücke (1999) also provides similar arguments. In summary, although the direction of correlation (complementarity or substitutability) between trade in imports and inward FDI is a matter of debate, nevertheless these two channels seem to be interlinked in encouraging productivity growth. However, no evidence exists with respect to the dynamics of knowledge spillovers from inward FDI and imports and how they interact with one another in promoting domestic productivity growth. The first and foremost contribution of the study reflects this consideration. The *a-priori* assumption here is that inward FDI encourages imports of technologically intensive intermediate goods and services from the parent country and transfers the capabilities to use technologically advanced products to workers hired from domestic labor market. Therefore, we expect a complementary relationship between the two spillover channels. Based on this expectation, we examine their individual as well as combined impact as spillover mechanism on domestic productivity growth and propose the following hypotheses:

Hypothesis 1a: Knowledge spillovers through imports positively affect domestic productivity.

Hypothesis 1b: Knowledge spillovers through inward FDI positively affect

domestic productivity.

Hypothesis 2: Knowledge spillovers through imports and inward FDI jointly affect domestic productivity.

2.2 Moderating Knowledge Spillovers: Human Capital

The relevance of trade and FDI as channels for knowledge transfer is crucial for productivity, to say the least. However, mere access to foreign R&D stock, technologies and know-how is not enough to drive a country on the path of long-term development. It is equally essential for the external knowledge to be sufficiently absorbed and diffused throughout the economy. Herein lies the role of human capital as a measure of absorptive capacity in moderating the relationship between productivity and knowledge spillovers, and forms the second most important contribution of the current study.

In their seminal paper on the two faces of R&D, Cohen and Levinthal (1989) argue that while existence of external knowledge linkages is beneficial, firms necessarily should have adequate level of absorptive capacity in order to materialize beneficial spillovers from such external linkages. Accordingly, firms should invest in the development of such absorptive capacity by undertaking internal R&D activities. Discussing absorptive capacity within a human capital framework, Nelson and Phelps (1966) propose that in a technologically progressive economy, the more educated the innovators are, the quicker will be the speed of introduction of new techniques of production, and this will subsequently speed up the process of technological diffusion. Postulating two theoretical models of technological diffusion, authors indicate that the payoff to increased educational attainment (that is the rate of return to education) is greater the more technologically progressive the economy is. Also, that while the growth of technology frontier reflects the rate at which new discoveries are made, the growth of TFP depends on the implementation of these discoveries and varies positively with the distance between the technology frontier and the level of current productivity, which again depends on the level of human capital. Following similar arguments, Engelbrecht (1997) builds upon CH's model by including human capital as an additional variable accounting for non-R&D related innovation activities. Measuring human capital by interpolating Barro and J.-W. Lee (1993) data on average years of education of the labor force above 25 years of age for 21 OECD countries, author finds a direct effect of this variable on domestic productivity, technology catch-up and in the absorption of foreign technology. Similar studies (Frantzen (2000), Griffith, Redding, and Simpson (2002), Barrios et al. (2007), Kwark and Shyn (2006), Teixeira and Fortuna (2010) also confirm these findings.

Absorptive capacity measured in terms of human capital is also related to the literature on spillover channels where researchers have established the relationship between domestic human capital stock, international trade and FDI. Miller and Upadhyay (2000) suggest that the impact of human capital in a country is conditioned upon the degree to which the economy is open to international trade. Using data for a sample of developed as well as developing countries, authors find that for low degrees of trade openness, the effect of human capital on total factor productivity is negative while for greater degrees of trade openness, the effect is positive and highly significant. While the relationship between trade and human capital is quite straightforward, the same cannot be said with respect to FDI. Borensztein, De Gregorio, and Lee (1998) claims that the productivity effect of FDI will depend on the educational characteristics of the host or receiving countries. Examining the effect of FDI on economic growth in a cross-country analysis during 1970-1989 and measuring human capital as average years of schooling of male pupils (Barro and J.-W. Lee 1993), author finds direct as well indirect effect of FDI on productivity growth. Not only does greater FDI raise productivity, but the magnitude of the effect depends significantly on the domestic human capital stock of the country. Similarly, Blomström, Kokko, and Mucchielli (2003) suggest that while FDI inflow leads to absorption and diffusion of foreign technology through upgradation of local skills, a host country's level of human capital also determines the level of FDI it attracts. In other words, a greater level of human capital should attract more technologically intensive FDI and MNC operations as compared to weaker economies with lower level of human capital and absorptive capacity. Thus the extent and scope of knowledge spillovers from FDI depend on the readiness and absorptive capability of the domestic sector. This means that while FDI reduces the cost of technology adoption, spillovers from FDI can also be negative because of crowding out effect on domestic firms with insufficient absorptive capacity. Other studies that investigate the complex and non-linear relationship between channels of knowledge spillovers and human capital (Kokko, Tansini, and Zejan 1996; Kathuria 2002) suggest that FDI affects domestic productivity only in the presence of technological and market capabilities, a certain threshold level of human capital, and investment in learning and training.

It is evident from the studies mentioned above that the interrelationship between the channels of knowledge spillovers through FDI and trade and human capital are already studied at various levels of aggregation. However, while theoretical predictions on the moderating role of human capital are substantial, empirical verification of the issue is mixed and rather inconclusive. The current study claims that the way human capital is measured in existing literature might be one reason for the mixed evidence. So far, in previous studies, human capital stock in a country is measured in terms of quantity-based indicators such as average years of schooling and graduation rates and then related to knowledge spillovers and productivity growth. However, quantity-based indicators of human capital fail to account for quality differences in the education system and dimensions related to skills and competencies of human capital (OECD 2001). By this measure, an additional year of secondary education in a developed country say the United States will be the same as in a less-developed country say Bangladesh, even though U.S. has a far superior education system that Bangladesh in terms of quality. Furthermore, it neglects the differences in cognitive skills and problem-solving capabilities in students (Hanushek and Kimko 2000) and therefore renders the measure incomparable across countries. What is needed, therefore, is a systematic analysis of the role of human capital taking into account the quality differences across countries that in turn affects the speed of absorption of knowledge spillovers through trade and FDI. To the best of our knowledge, no studies have so far provided a quality measure of human capital in analyzing the productivity effects of knowledge spillovers. Addressing this limitation, the paper uses secondary data for human capital based on average years of schooling and returns to education and adjusts it for quality using patents and publications. The following section explains the quantity-quality indicators and the choice of proxies for human capital measurement in more details.

2.3 Quantity vs. Quality of Human capital

Traditionally, three approaches to human capital measurement have been pursued in the literature: cost-based approach, income-based approach and indicator-based approach. The cost-based approach (Kendrick 1976; Eisner 1988) measures human capital in terms of past investments undertaken by individuals, households, employers or government, and more recently in terms of the value of time devoted to the education of students. The income-based approach (Weisbrod 1961; Graham and Webb 1979; Jorgenson and Fraumeni 1989) measures human capital as the expected future earnings generated from human capital investments over the lifetime of a person. Finally, the indicator-based approach uses various measures as proxy for the stock of human capital- for example, school enrollment rates (Barro 1991; Mankiw, Romer, and Weil 1992; Levine and Renelt 1992), educational attainment of adults aged 25 years and above (Barro and J.-W. Lee 1993), average years of schooling (Benhabib and Spiegel 1994; Barro and Sala-i-Martin 2004; O'Neill 1995; Barro 1996; Krueger and Lindahl 2000), student-teacher ratio (Wang and Wong 2011), graduation rates, dropout rates and adult literacy rates (Azariadis and Drazen 1990; Nehru, Swanson, and Dubey 1995; Barro and J. W. Lee 1996). However, these measures fail to account for differences in education system across countries and attach equal weights, irrespective of quality differences and mismatch in the cognitive skills of students. Because quality of human capital, and not mere quantity, is an important indicator of economic growth, the current study provides a new measure of human capital stock adjusted by its quality and subsequently examines its effect in moderating the relationship between knowledge spillovers and productivity.

One approach that has gained much attention in recent years as a quality-based measure of human capital is international test scores that capture the cognitive performance of students globally (Hanushek and Kimko 2000). For example, the Trends in International Mathematics and Science Study (TIMSS) is a worldwide study program provided by the International Association for the Evaluation of Educational Achievement (IEA) that assesses mathematics and science knowledge in 4th and 8th grade students. The study, first conducted in 1995 and thereafter conducted every four years globally, provides additional information on the learning conditions in countries and hence accounts also for the diversity in the education systems worldwide. A similar assessment program provided by the OECD is the Programme for International Student Assessment (PISA) that tests cognitive skills like reading, mathematics, science and problem solving of 15-16 year olds. This program, started in 2000 and repeated every three years, aims at measuring "education's application to real-life problems and lifelong learning" (OECD 2001). Another recent international study provided by the OECD is the Programme for the International Assessment of Adult Competencies (PIAAC) that tests skills and competencies of adults (aged 16-65) in terms of literacy, numeracy and problem-solving in technology-rich environments. PIAAC, first conducted in 2011-2012 in the U.S., therefore allows for systematic comparison across countries by focusing on the cognitive and workplace skills, educational background and occupational attainment of adults around the world. Other similar examples of standardized tests are the Graduate Record Examinations (GRE), the Graduate Management Admission Test (GMAT) and the Scholastic Aptitude Test (SAT). Although most of these standardized tests provide time series across educational assessments for countries, availability of annual data for a longer time frame and for all sample countries considered in the current analysis is a major issue. The International Mathematical Olympiad (IMO) serves as an alternative, by providing yearly scores in mathematics for pre-collegiate students worldwide. The IMO, first held in 1959 in Romania, is a 42-point mathematical Olympiad that ranks countries based on the cumulative test scores. It is not a proxy for basic skills in the population, rather a proxy for the beyond-the-classroom education a country provides to exceptionally high-skilled students in mathematics and science. IMO test scores are available for long time periods and for all our sample countries, with the only limitation arising from the structure of the test and sample-size[3].

A second alternative in this regard is journal publications. An academic journal is a peer-reviewed periodical that constitutes publication of original research, review articles and book reviews in all fields of academia. It is frequently used as a proxy for the scientific environment, and the research activities undertaken in a country. Typically, the quality of an academic journal is measured by its 'impact factor', that is the average number of citations received from later publications, and journals with higher impact factors are considered to be of higher quality than those with lower ones. Therefore, one can assume that higher the number of journal publications in a country, the richer is its knowledge base and human capital. Furthermore, data on publication is readily available for all countries in the sample for a long time frame.

Third alternative is patents. Patents are generally used as a proxy for innovativeness in regional- and firm-level analysis. Although patents are direct measure of innovative activity, they still suffer from some potential problems. Despite being very narrow in scope, patents can be used as a proxy for quality of education. Countries with better quality of education are more likely to innovate than countries with poorer quality. Therefore, relatively higher number of patents in a given year can hint towards better education system in countries.

Subsequently, the current analysis uses data from World Bank for journal publications in science and technology (S&T, having non-zero impact factors), and patent applications as weighing parameters for Barro and J.-W. Lee (2010) quantity-based measure of human capital. The details of the construction can be found in the data section, however, figure 1 shows how the respective positions of the countries changes when we adjust the conventional measure of human capital with quality. We rank 20 countries in our sample based on both adjusted and unadjusted human capital indices and subtract their respective ranks for 1995 and 2010. The figure shows the plots of differences in relative ranks of 20 European countries in the sample. The positive differences are the gains in ranks after adjustment for quality, which already points to the fact that conventional human capital index underestimated the human capital of these countries and vice versa. Most significant differences are observed for Czech Republic for which

3. Please see Appendix for an overview on pros and cons of using the different proxies for quality adjustment of human capital.

the rank drops from 1st to 13th in 1995 and 1st to 15th in 2010. Similarly, Estonia goes down in the ranks from 8th to 18th in 1995 and 3rd to 19th in 2010. However, rank for United Kingdom increases from 18th to 4th in 1995 and 20th to 4th in 2010. Therefore, quality-adjusted ranks show the more realistic position of the countries in terms of quality of their academic institutions.

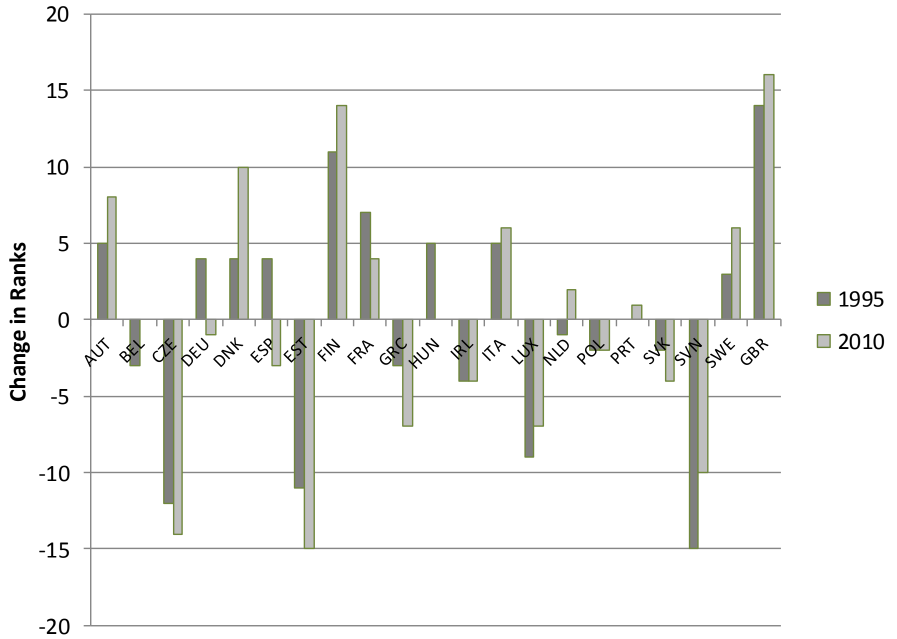

Figure 1: Change in ranks after quality adjustment of human capital

Based on these differences, the second contribution of the study is the analysis of the moderating role of quality-adjusted human capital in the knowledge spillover-productivity link. If imports, for example, are technology intensive and the importing country does not have adequate human capital to learn from the knowledge embedded in the imports, then spillovers will not adequately affect overall productivity of the economy. Proposing similar arguments with respect to FDI, it can therefore be argued that countries with better human capital benefit more from knowledge spillovers through channels of trade and FDI. We assess the moderation of human capital using interactions between knowledge spillovers and quality-adjusted human capital and propose the following hypothesis:

Hypothesis 3: Human capital positively moderates the relationship between knowledge spillovers and domestic productivity.

Finally, in a cross-country analysis it is important to assess the heterogeneous country specific characteristics. Countries at different growth trajectories than others might benefit differently from the knowledge spillovers relative to their level of productivity. According to the catching-up hypothesis, countries with productivity levels significantly lower than the frontier are expected to gain more from knowledge spillovers than the countries closer to the frontier (Griffith, Redding, and Simpson 2002; Castellani and Zanfei 2003). This is because technologically-backward countries benefit from imitation of technologies introduced in leader countries, and usually the cost of imitation is lower than that of innovation closer to the frontier (Barro and Sala-i-Martin 2004). Therefore, wider the technology gap between the lagging country and the leader, higher is the scope of technology adoption and knowledge spillovers and subsequently higher the gains in productivity. We capture this effect by introducing technological gap variable in the main regressions and also interact it with the spillovers variables to assess whether countries far away from the technological frontier gain more from knowledge spillovers.

Hypothesis 4: Countries significantly distant from the technological frontier gain more from knowledge spillovers.

3 Models

3.1 Model 1: CH Specification

The main model to test our hypotheses 1a and 1b builds upon CH specification (corresponding to equation 2 in the CH) and is formulated as follows:

$$logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \epsilon_{i,t} \tag{1}$$

where TFP is total factor productivity of country i, $R\&D_{i,t}$ is per capita R&D stock in importing country (country i), $ImportSpill_{i,t} = \Omega \text{logR\&D}_{j,t}$ represent per capita import-related spillovers where $R\&D_{j,t}$ is stock of R&D in exporting country (country j) and Ω is the fraction of imports in GDP in country i.

3.2 Model 2: Base Specification (Extension of Model 1)

We extend CH model in equation 1 by including quality-adjusted human capital and FDI as an additional source of international knowledge spillovers in equation 2.

$$logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \beta_3 \text{FDI}_{i,t} + \beta_4 \text{HCQ}_{i,t} + \epsilon_{i,t} \tag{2}$$

where HCQ is the quality adjusted human capital variable and FDI is per capita stock of inward FDI in country i.

3.3 Model 3: Complementarity Between Import-Related Spillovers and FDI

Model 3 aims to capture the complementarity between import-related spillovers and FDI as outlined in hypothesis 2. The interaction between import-related spillovers and FDI is used to determine whether import-related spillovers and FDI are complements or substitutes of each other.

$$\begin{aligned} logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \beta_3 \text{FDI}_{i,t} + \beta_4 \text{HCQ}_{i,t} + \\ \beta_5 (\text{ImportSpill}_{i,t} * \text{FDI}_{i,t}) + \epsilon_{i,t} \end{aligned} \tag{3}$$

3.4 Model 4: Human Capital as a Moderator of Knowledge Spillovers

Interactions of import-related spillovers and FDI with quality-adjusted human capital are introduced in Model 4[4]. Here we aim to test our hypothesis 3 where we expected human capital to moderate the relationship between knowledge spillovers and TFP.

$$logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \beta_3 \text{FDI}_{i,t} + \beta_4 \text{HCQ}_{i,t} + \beta_5(\text{ImportSpill}_{i,t} * \text{HCQ}_{i,t}) + \beta_6(\text{FDI}_{i,t} * \text{HCQ}_{i,t}) + \epsilon_{i,t} \tag{4}$$

3.5 Model 5: Role of Technological Gap

Finally, in Model 5, to test our hypothesis 4, we include the technological gap between country i and the technological frontier in model 2 (equation 5a below).

$$logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \beta_3 \text{FDI}_{i,t} + \beta_4 \text{HCQ}_{i,t} + \beta_5 \text{GAP}_{i,t} + \epsilon_{i,t} \tag{5a}$$

Where GAP is the distance between country with $highestTFP$ in the sample *minus* TFP of country i. In subsequent models, we include interactions of GAP variable with import-related spillovers and FDI to test whether technologically distant countries benefit more from international knowledge spillovers (models 5b and 5c).

$$logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \beta_3 \text{FDI}_{i,t} + \beta_4 \text{HCQ}_{i,t} + \beta_5 \text{GAP}_{i,t} + \beta_6(ImportSpill_{i,t} * \text{GAP}_{i,t}) + \epsilon_{i,t} \tag{5b}$$

$$logTFP_{i,t} = \beta_0 + \beta_1 \text{logR\&D}_{i,t} + \beta_2 \text{ImportSpill}_{i,t} + \beta_3 \text{FDI}_{i,t} + \beta_4 \text{HCQ}_{i,t} + \beta_5 \text{GAP}_{i,t} + \beta_6(\text{FDI}_{i,t} * \text{GAP}_{i,t}) + \epsilon_{i,t} \tag{5c}$$

4 Data

The data sample covers the period from 1995 to 2010 and includes 20 European countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Spain, Slovak Republic, Slovenia, Sweden and United Kingdom. In what follows, we explain the construction and sources of the variables used in our empirical analysis.

4.1 Total Factor Productivity (TFP)

Total factory productivity is taken from Penn World Tables v8.0 and the following methodology has been used to calculate TFP:

$$TFP_{i,t} = \frac{Y_t}{Y_{t-1}} / Q_{t,t-1}$$

4. It is important to note here that, we do not include several interaction terms in a single equation given the potential problem of interpreting one single variable in multiple interactions.

where

$$Q_{t,t-1} = \frac{1}{2}(\alpha_t + \alpha_{t-1})ln\frac{K_t}{K_{t-1}} + [1 - \frac{1}{2}(\alpha_t + \alpha_{t-1})]ln\frac{L_t}{L_{t-1}}$$

Y is real GDP, K is capital stock, L is labor force engaged and α is output elasticity of capital (share of gross fixed capital formation in real GDP). Details of the calculation can be found in Inklaar and Timmer (2013).

4.2 R&D Capital Stock

Since data for R&D capital stock is not available for long time series, we calculate R&D capital stock using perpetual inventory method for each country. Data for R&D flows is taken from OECD to estimate stock values, and subsequently R&D capital stock for the first year is calculated using following formula:

$$R\&D_{i,t=1} = \frac{R\&D^{flow}_{i,t=1}}{g + \delta} \tag{6}$$

where $R\&D^{flow}_{i,t=1}$ is R&D expenditure flow for the first year, g is compound annual growth rate of R&D expenditure flows and δ is depreciation rate of investment assumed at 15%.

Although our sample for estimations starts from 1995, for calculation of R&D capital stock, we use data from 1981 to minimize the potential bias in the construction of the first year's capital stock. For some countries such as Czech Republic and Estonia, available data series starts from 1991 and 1998, respectively. In such cases, initial capital stock is calculated for available years and linearly extrapolated wherever necessary. Similarly, linear interpolation is used to fill-in missing values of R&D expenditure flows. Capital stock for later years is calculated by adding the flow of R&D expenditure to the previous year's capital stock after adjusting it for depreciation. Formally:

$$R\&D_{i,t} = R\&D_{i,t-1} * (1 - \delta) + R\&D^{flow}_{i,t}$$

4.3 Human Capital Variables

The unadjusted human capital index is taken from Penn World Tables v8.0. This index is based on averages years of schooling from Barro and J.-W. Lee (2010) and assumed rate of return corresponding to Psacharopoulos (1994). Human capital variable based on above mentioned criteria provides meaningful information about quantity of human capital for population above 15 years of age. However, it does not account for quality of education. This caveat of the index limits its usefulness in cross country analysis, following which we weight human capital variable with proxies of quality of education. The variables used as proxy for quality of education (as explained in section 2.3) are a) aggregated journal articles in science and technology (World Development Indicators (WDI)) and b) aggregated patents (WDI). The benefit of using aggregated patents and publications from WDI compared to web of science database is that OECD data is weighted for co-authorship. If there are more than one author for a publication or a patent, OECD distributes the share to all co-authors to avoid double counting. The quality adjusted human capital (HCQ) variable is calculated using equation 7.

$$HCQ = HC * (\frac{Publications}{L} + \frac{Patents}{L}) \tag{7}$$

where HC is the human capital index based on average years of schooling and returns to education, *publications* is the journal publications in science and technology from World Bank, *patents* is number of patent applications per country in all fields and L is the engaged labor force.

4.4 Knowledge Spillovers

In context of this study, knowledge from one country to another is transferred through the channel of imports and FDI. Countries spend on R&D to develop new knowledge. The pieces of new knowledge from R&D activities over the years jointly represent knowledge stock of the country. Therefore, we use R&D capital stock as a proxy for knowledge stock of a country. Some component of the overall knowledge stock is embodied in every product a country produces. Therefore, by exporting its products to other countries, country also shares some of its knowledge with the importing country. Formally:

$$ImportSpill_i = \sum_{j=1}^{n-1} \frac{Imports_{i,j}}{Y_i} logR\&D_j \tag{8}$$

where *Imports* represent imports of country i from country j. Y is the real GDP of country i and R&D$_j$ is R&D capital stock of country j.

We use bilateral imports data to calculate import-related spillovers for each country in each year. Spillovers are then aggregated across partners to calculate overall spillover index for each country i. Assuming that knowledge embodied in technologically intensive products is larger than primary commodities, we expect spillovers to be greater for industries with high level of technology and restrict our analysis to high-technology and medium-high-technology imports according to the OECD intensity classifications[5].

Calculation for knowledge spillovers through FDI ideally should also follow similar strategy as explained above. However, in absence of quality data in bilateral FDI flows, such calculation is not possible. Therefore, we use stock of inward FDI to approximate the knowledge flows through FDI.

4.5 Technological Gap

Growth theory suggests that countries that are technologically distant from the frontier, tend to catch-up faster than the technologically proximate countries. In order to capture this effect, we use technological gap GAP variable as shown in equation 9. The GAP

5. ISIC Rev.2 Technology Intensity (See table A1 in Appendix)

variable for each country i in each year t is the difference between the TFP of the TFP leader and the TFP of country i for each time period t.

$$GAP_{i,t} = \frac{TFP_{leader,t} - TFP_{i,t}}{TFP_{leader,t}} \tag{9}$$

where $TFP_{leader,t}$ is the TFP of technological leader at time t and $TFP_{i,t}$ is the TFP of country i at time t (2005=1). Table 3.1 provides an overview of the per capita variables used in the analysis.

Table 1: Descriptive Statistics (Per capita variables)

	Log(TFP)	Log(R&D)	ImportSpill	Log(HCQ)	Log(FDI)	Log(Gap)
Mean	-0.031	-5.843	0.034	11.874	8.702	0.394
Median	-0.016	-5.882	0.018	11.886	8.746	0.438
Maximum	0.141	-1.712	0.274	14.677	11.397	0.650
Minimum	-0.406	-9.767	0.000	7.700	5.317	0
Std. Dev.	0.077	1.684	0.049	1.483	1.165	0.176
Skewness	-1.333	0.428	2.761	-0.399	-0.192	-0.909
Kurtosis	6.126	2.697	11.241	3.061	2.761	2.889
Jarque-Bera	225.078	10.990	1312.107	8.554	2.730	44.315
Probability	0.000	0.004	0.000	0.013	0.255	0.000
Observations	320	320	320	320	320	320

5 Empirical Methodology

Dataset used in the current study is a panel of 20 European countries from 1995 to 2010. The natural candidates for estimation method in case of panel data are fixed or random effects models which are designed to account for unit heterogeneity. However, there are atleast two potential econometric problems that these methods do not account for. Firstly, the relationship between TFP and knowledge spillovers may not be unidirectional. Possible reverse causality in this case can result in endogeneity where a crucial assumption of classical linear regression model $cov[\text{X},\epsilon] = 0$ is violated and resulting estimates are biased. Secondly, variables used in our models have strong deterministic trend (Figure 2, 3, 4, 5 and 6 in Appendix), the presence of which can result in spurious correlation. To avoid this problem, previous studies use variables in differences. However, by taking differences, important information embodied in the variables is lost (Coe and Helpman, 1995).

In order to account for country specific effects and endogeneity in absence of ideal set of instruments at hand, generalized method of moments (GMM) provides a useful alternative. GMM uses lag structure of endogenous and predetermined variables to account for endogeneity and allows for dynamic modeling using lagged dependent variable. However, since GMM is designed for small T and large N, our N=20 may not be large enough to satisfy this condition. Moreover, GMM is not designed to account for long-run relationship in presence of cointegration. Dynamic OLS provides a solution to the problems mentioned above that is it accounts for country specific effects, endogeneity as well as long run cointegrating relationship. Estimation using cointegration approach produces unbiased estimates without losing important information contained in data at levels. This procedure requires all variables to be I(1) (integrated of order 1). Moreover, the variables are said to be cointegrated when residual of the equations of interest are stationary. In other words, cointegration techniques for estimation can only be applied when all variables are stationary at first difference and their linear combination (residual) is stationary. In panel settings, number of tests can be applied to test for unit-root as well as for cointegration. Most commonly used cointegration tests in panel data context are Pedroni (1999), Pedroni (2004) and Kao (1999) tests for cointegration. Both tests use similar approaches but are based on slightly different assumptions. A brief overview of cointegration concept as well as tests for cointegration are presented in Appendix 8.1. There are two classes of panel unitroot tests; one assumes a common unit root process for all cross sections (eg Levin, Lin, and James Chu 2002, Breitung 2000) and the second one allows for individual unit-root processes (eg Im, Pesaran, and Shin 2003 (IPS), Fisher-type Dickey and Fuller 1979 (ADF) and Phillips and Perron 1988 (PP)). The assumption of common unit root process across cross-section can be too restrictive (Barreira and Rodrigues 2005). Therefore, we rely on IPS, ADF and PP tests for unitroot. Null hypothesis for these tests is the presence of unit root.

Table 2: Unitroot Tests

Variables	**IPS* Test (W-stat)**	**ADF Test (Chi-Square)**	**PP Test (Chi-Square)**
log(TFP)	0.96	37.25	30.82
Δlog(TFP)	-3.36***	76.68***	107.1***
log(R&D)	1.19	42.8	22.18
Δlog(R&D)	-3.76***	78.3***	153.25
ImportSpill	-1.44	18.94	17.09*
ΔImportSpill	-4.94***	95.04***	161.83***
log(HCQ)	3.67	24.15	44.57
Δlog(HCQ)	-3.23***	72.16***	180.59***
log(FDI)	3.24	17.68	16.34
Δlog(FDI)	-4.34***	88.63***	181.72***
log(Gap)	1.29	41.82	42.31
Δlog(GAP)	-2.41***	68.68***	142.7***
logR&D	1.29	51.34	21.81
ΔlogR&D	-3.22***	74.76***	153.54***
ImportSpill(abs)	-1.23	49.11	51.09
ΔImportSpill(abs)	-5.04***	96.54***	164.99***
log(HCQ*Pop)	2.90	27.6	50.09
Δlog(HCQ*Pop)	-1.77**	54.96*	161.06***
log(FDI(abs))	0.46	27.92	28.84
Δlog(FDI(abs))	-2.33***	62.67**	140.89***

Ho: Variables contain unitroot. p-values in parenthesis
Variables marked with (abs) represent absolute values i.e. not in per-capita form
*IPS: Im-Pesaran-Shin; ADF: Augmented-Dickey-Fuller; PP: Phillip-Perron

6 Estimation Results

Estimation using panel cointegration methods, as explained in the previous section, requires all variables to be integrated of order 1 (non stationary at levels but stationary at first difference) as well as their linear combination to be integrated of order zero (that is the resulting residuals should be stationary at levels). The results of Pedroni and Kao tests for panel cointegration are presented under each model. Unlike Kao test, Pedroni test provides 11 test statistics under assumptions of joint unit root and individual unit root processes across cross sections. There is, however, no clear guideline on the decision rule to conclude about existence of cointegrating relationship. Moreover, the assumption of common autoregressive process could be too restrictive (Barreira, 2005). Given these limitations, we rely, in addition to 11 test statistics of Pedroni, on Kao test for cointegration. In most cases, 7 out of 12 tests show that the variables are cointegrated. The results of unitroot tests are provided in Table 2. The null hypothesis for the tests is the existence of unitroot. Test statistics show that all variables are non-stationary at levels and stationary at first difference (that is, they are I(1)) which is one of the necessary conditions for the use of cointegration estimation method that we use next.

Estimation results of the models are summarized in Table 3. Model 1, corresponding to equation 1 in theory section, confirm the findings of CH. Increase in domestic R&D capital stock significantly increases TFP in European countries. Similarly, import related knowledge spillovers also have positive relationship with TFP. The results show (confirming the findings of CH) that in addition to domestic R&D efforts, knowledge spillovers through imports in high and medium tech sectors are also important for TFP in importing countries. In model 2 we extend the CH model by including quality adjusted human capital and FDI stock. Increase in stock of human capital is expected to improve TFP as labor with better human capital is expected to be more productive. Similarly, FDI stock is expected to improve TFP if knowledge embodied in the multinationals is reflected in the TFP of domestic firms. Our results show support for the arguments above, that is, increase in quality adjusted human capital and FDI stock increases TFP in host countries. Addition of these two variables improves the findings of CH by showing that human capital and FDI stock also significantly explain variation in TFP and therefore should be included in the model. Additionally, the overall model fit increases from 0.874 (model 1) to 0.978 (model 2), supporting the argument.

Model 3 tests for the complementarity between import-related spillovers and FDI (hypothesis 2). Studies on the complementary relationship between imports and FDI provide mixed evidence, on technologically intensive multinationals importing hi-tech merchandise and intermediate inputs from their home countries in the absence of suitable production facilities in the host country on the one hand, and increased inward FDI substituting imports of finished goods and services on the other. The current study contributes to understanding the exact relationship, with an *a-priori* expectation that in the context of knowledge spillovers, by importing hi-tech manufacturing goods, FDI not only brings potential sources of external knowledge but also diffuses the know-how to use hi-tech manufacturing goods. Following this line of argument, we expect import related spillovers and FDI to complement each other and we test for the complementarity using interaction between import related spillovers and FDI in the main model. The positive and significant coefficient of interactions shows support for the complementarity hypothesis. In other words, results show that not only do import related spillovers and FDI affect TFP but also their joint effect raise domestic productivity. These findings confirm hypothesis 2 and form the first major contribution of the study. Switch of sign from positive to negative for import-related spillovers deserves an explanation. Since interpretation of main effects have to be interpreted jointly with the interaction term, the joint effect should be positive. FDI variable was rescaled for better interpretation of the interaction term. Since resulting magnitude of overall effect is positive (0.560-0.422) we conclude that there is positive interaction effect, that is, FDI and import-related spillovers are complementary to each other.

Table 3: Estimation Results

	Model(1)	Model(2)	Model(3)	Model(4)	Model(5a)	Model(5b)	Model(5c)
log(R&D)	0.267***	0.187***	0.262***	0.131***	0.206***	0.255***	0.218***
	(0.034)	(0.027)	(0.023)	(0.026)	(0.025)	(0.027)	(0.025)
ImportSpill	0.136***	0.738***	-0.422***	-0.909***	0.658***	0.759***	0.427
	(0.037)	(0.204)	(0.059)	(0.096)	(0.158)	(0.157)	(0.423)
log(HCQ)		0.380***	0.255***	1.090**	0.403***	0.381***	0.457***
		(0.042)	(0.033)	(0.043)	(0.042)	(0.046)	0.040
log(FDI)		0.056***	0.320***	-0.054	0.06***	0.054***	0.063***
		(0.004)	(0.004)	(0.041)	(0.005)	(0.005)	(0.004)
log(FDI)* Log(HCQ)				0.009***			
				(0.003)			
ImportSpill * Log(HCQ)				1.120***			
				(0.011)			
log(FDI)* ImportSpill			0.560***				
			(0.007)				
logGap					0.033*	-0.001	0.037**
					(0.014)	(0.086)	(0.013)
log(FDI)*logGap						0.007	
						(0.009)	
ImportSpill *logGap							0.181
							(0.616)
R^2	0.898	0.965	0.977	0.974	0.973	0.978	0.978
Adjusted R^2	0.874	0.978	0.971	0.969	0.967	0.973	0.974
No of Observations	300	300	300	300	300	300	300
Pedroni	5 out of 11	6 out of 11	6 out of 11	6 out of 11	6 out of 11	5 out of 11	5 out of 11
Kao Cointegration Test	-1.94**	-2.43**	-3.66***	-4.24***	-2.91***	-2.75***	-3.46***

Dependent variable is log(TFP). *p<0.10 **pp<0.05 ***pp<0.01
Null hypothesis for cointegration test is "no cointegration"
(Pedroni test results presented above are number of significant test results out of 11)

In model 4 we test our hypothesis 3 where we include interactions of human capital with FDI stock and import related knowledge spillovers. The purpose of this model is to test whether human capital moderates the relationship between knowledge spillovers and TFP. Countries with better human capital are expected to gain more from knowledge spillovers through external sources as it is easier for them to absorb the inflow of knowledge. Positive and significant coefficients of interaction terms, both with import related knowledge spillovers and with FDI stock, confirm hypothesis 3. In other words, results confirm that countries with better quality of human capital benefits not only from direct effects of productivity, but also from productivity effects from international knowledge spillovers. Similar to the explanation above, import-related spillover variable was rescaled for ease of interpretation. Since joint effect is positive, we conclude that the interaction is positive. This two-way contribution of human capital in domestic productivity constitutes the second major finding of the study, and reaffirms the necessity of using quality-adjusted human capital measures in cross-country analysis.

Final three models (5a, 5b and 5c) test our final hypothesis concerning the technological distance with frontier. We hypothesize that relationship between international knowledge spillovers and TFP is stronger for technologically-lagging countries. Technological distance (Gap) determines the potential to improve, implying that countries too distant from the frontier may not learn too much due to the lack of absorptive capacity while countries too close to the frontier may not have much to learn from the exporting (investing) partner. Existence of such a non-linear relationship can be tested using quadratic version of technological gap in the model. We, however, could not find support for the quadratic relationship. The linear version of technological gap variable has been introduced in model 5a. Positive and significant coefficient shows that technologically distant countries catch-up faster than the ones closer to the frontier. In model 5b and 5c we introduce interactions of technological gap with FDI and import related spillovers. Using similar line of arguments, we expect technologically distant countries to have stronger relationship between international knowledge spillovers and TFP as they have more to learn than countries technologically-proximate to the frontier. Surprisingly, the results do not show support for the hypothesis. Both interactions, FDI with gap variable and import related spillovers and gap, do not appear to have significant relationship with TFP. In other words, the result shows that the relationship between international knowledge spillovers and TFP does not vary with the change in technological distance with frontier.

7 Conclusion

The endogenous growth literature suggests that while own R&D efforts as well as foreign R&D transmitted through channels of knowledge spillovers are necessary for explaining domestic productivity growth, it is not a sufficient condition. In order to understand the underlying mechanism through which international knowledge spillovers affect domestic productivity, it is essential to accommodate human capital in the analysis. However, existing literature on the relationship between human capital and channels of knowledge spillovers provide mixed and inconclusive evidence, pointing towards methodological limitations associated with using quantity-based physical indicators of human capital to assess cross-country differences. The current study takes the cue from this backdrop and proposes a quality-based indicator of human capital that incorporates quality-differences in the education system in countries. Furthermore, it incorporates inward foreign direct investment as an additional spillover channel and evaluates the findings of CH on domestic productivity. Finally, the extent to which knowledge spillovers from international trade and FDI overlap in shaping domestic productivity in the presence of human capital is examined.

Employing cointegration estimation procedure on 20 European countries during 1995-2010, the productivity enhancing effects of FDI-related spillovers as well as import-related spillovers are confirmed. Looking closely at the inter-relationship between knowledge spillovers from trade and inward FDI, our results provide strong support for a complementarity hypothesis between the two. This suggests that not only do these channels directly affect domestic productivity through greater knowledge spillovers, they also complement each other resulting in larger overall impact on productivity. The results are robust to model specifications, and to the best of our knowledge, constitutes the first novel finding of this study. With respect to human capital, we construct a quality-adjusted indicator by weighing Barro and J.-W. Lee (2010) quantity-based measure with S&T journal publications and patent applications, and find direct as well as moderating effect of human capital on domestic productivity. Last but not least, we investigate the catching up hypothesis to test whether technologically lagging countries benefit more from knowledge spillovers than countries closer to the technological frontier. However, contrary to our *a-priori* expectation, we do not find support for this argument both for FDI and import-related spillovers.

While providing important implications relating to the literature on economic growth and human capital, our study is not free from limitations. First, the use of publications and patents as the proxy for quality of education also has its limitations. Since publications largely represent only small proportion of highly qualified academicians, it is difficult to generalize the results to the whole population especially in case of developing countries. However, since we do do not have so-called developing countries in our sample, this problem might not be significant. Similarly, patents represent very specific type of innovative activity which can be patented. The standardized tests such as TIMSS can be used as more generalizable quality proxies subject to data availability. Second, our analysis can be greatly improved by use of bilateral industry level data. In absence of rich database at this moment, it is not possible to estimate knowledge component of FDI using CH methodology. Third, since our sample covers 20 European countries, external validity is limited. Finally, future research can also point towards explaining the phenomenon on micro- and meso-levels of analysis.

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8 Appendix

8.1 Brief overview of cointegration

Data in macroeconomics generally possess strong deterministic trend especially when there is a sufficiently long time series. The variables in such cases are generally non-stationary (that is they do not have constant mean and variance over time). In time series, when variables are non-stationary, conventional estimation techniques, such as ordinary least squares, are expected to be driven by spurious correlation (Phillips 1986). Engle and Granger (1987) show that linear combination of two or more I(1) (non-stationary) variables could be I(0) (stationary) in which case the series are said to be cointegrated. In other words, non-stationary variables are said to be cointegrated if the residuals from their relationship are stationary. By using cointegration, one can use full information embodied in the variables and also use the attractive properties of cointegration techniques such as super consistency when n goes to infinity (Stock 1987). Estimates generated by ordinary least squares, however, do not follow asymptotic Gaussian distribution, therefore standard testing procedures are invalid unless they are significantly modified. Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) are generally considered as an alternative to simple OLS in presence of cointegration. Since our data contains relatively large macroeconomic time series dimension of 16 years, we test our variables for unit root, the presence of which motivates the test for cointegration.

In time series, Engle and Granger (1987) cointegration test is used on I(1) variables to test for cointegration. If the residuals from the regression are I(0) then the variables are said to be cointegrated. On similar principle, Pedroni (1999), Pedroni (2004) and Kao (1999) propose cointegration tests for panel data. Pedroni test consists or several tests under different assumptions on constants and trends across cross-sections. Consider following regression:

$$y_{i,t} = \alpha_i + \delta_i \mathrm{t} + \beta_1 \mathrm{x}_{1i,t} + \beta_2 \mathrm{x}_{2i,t-1} + \beta_M \mathrm{x}_{Mi,t} + \epsilon_{i,t} \tag{10}$$

The variables x and y are assumed to be I(1). The individual constant and trends are represented by α and δ, respectively. Null hypothesis of the test is 'no cointegration'. In case of no cointegration, residuals ϵ are integrated of order 1. If ϵ is I(0) then the variables are said to be cointegrated. Formally, null hypothesis of no cointegration implies $\rho = 1$ in equation 11

$$\epsilon_{i,t} = \rho_i \epsilon_{i,t-1} + u_{i,t} \tag{11}$$

Pedroni proposes two sets of hypotheses for between and within dimension. Under the test for between dimension, the test allows for different cointegrating relationships across cross-sections while under the test for within dimension the cointegrating relationship is assumed to be homogenous across cross sections. Eleven statistics are calculated for Pedroni test under the assumptions described above. For decision rule, however, there is no concrete guideline for how many tests out of eleven should show cointegrating relationship. In this study, we reject the null of no cointegration if six out of eleven statistics of Pedroni reject the null of cointegration. Kao (1999) uses the similar approach as of Pedroni but allows for cross section specific constants and homogenous coefficients in the first stage regressions. Null hypothesis, similar to Pedroni test, is no cointegration. For robustness of the results, we have used both Kao and Pedroni tests for cointegration.

Country-wise time plots of variables

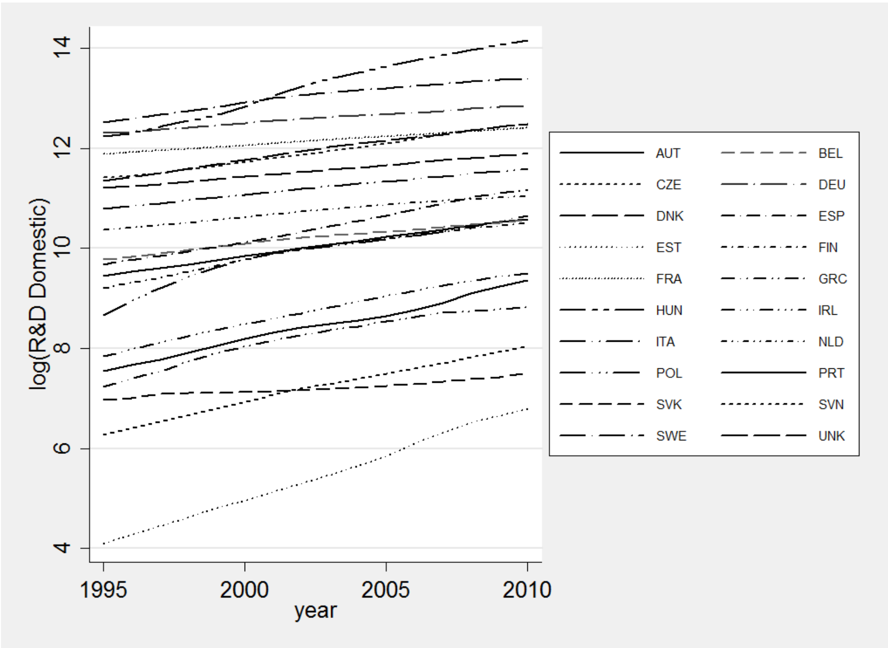

Figure 2: Log(R&D Domestic)

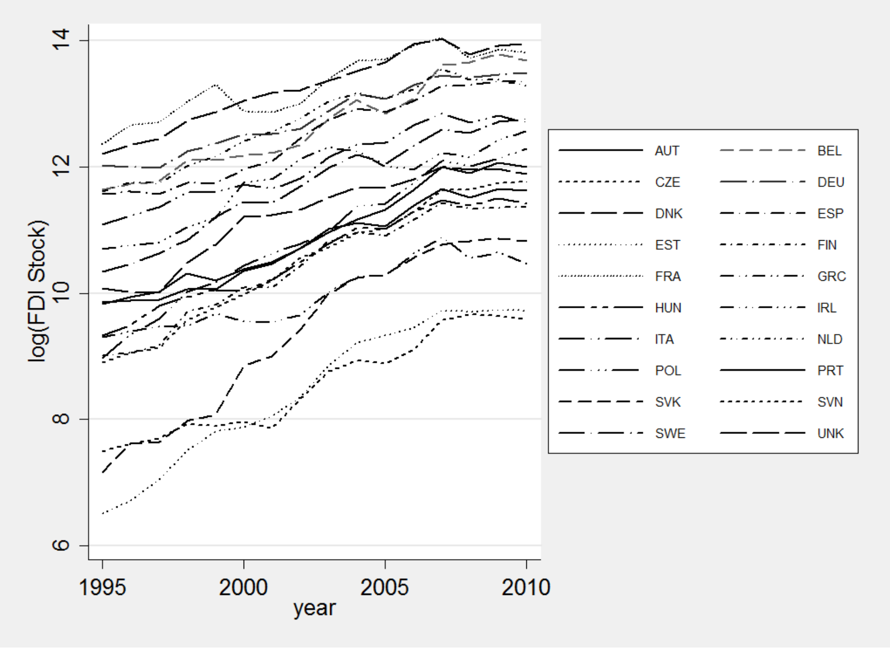

Figure 3: Log(FDI Stock)

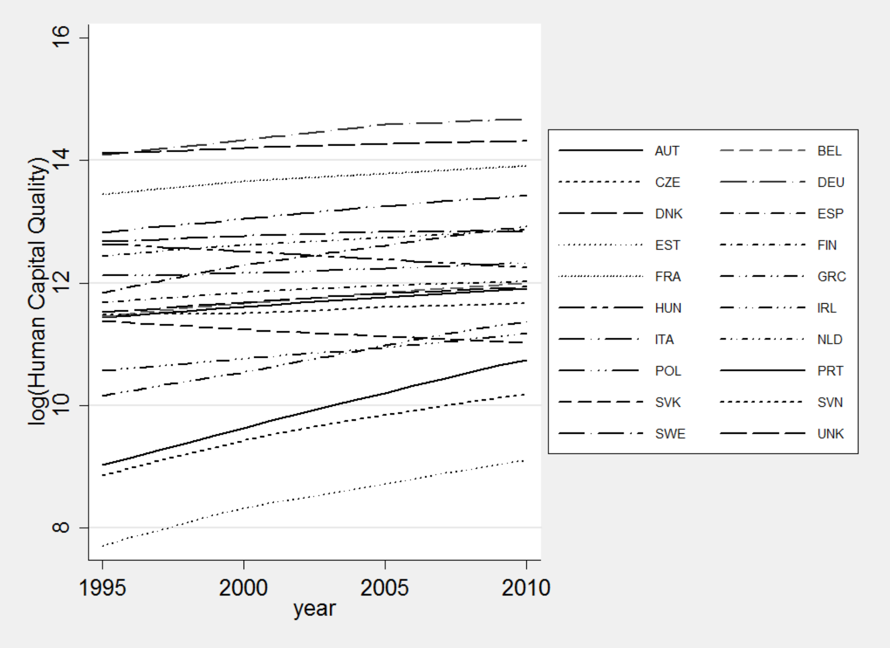

Figure 4: Log(Human Capital Quality)

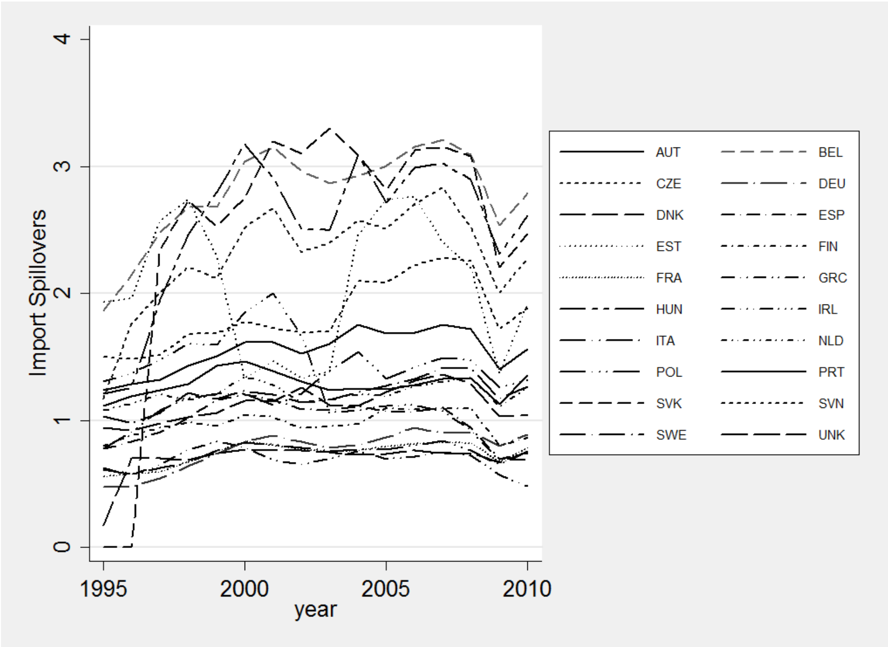

Figure 5: Import Related Spillovers

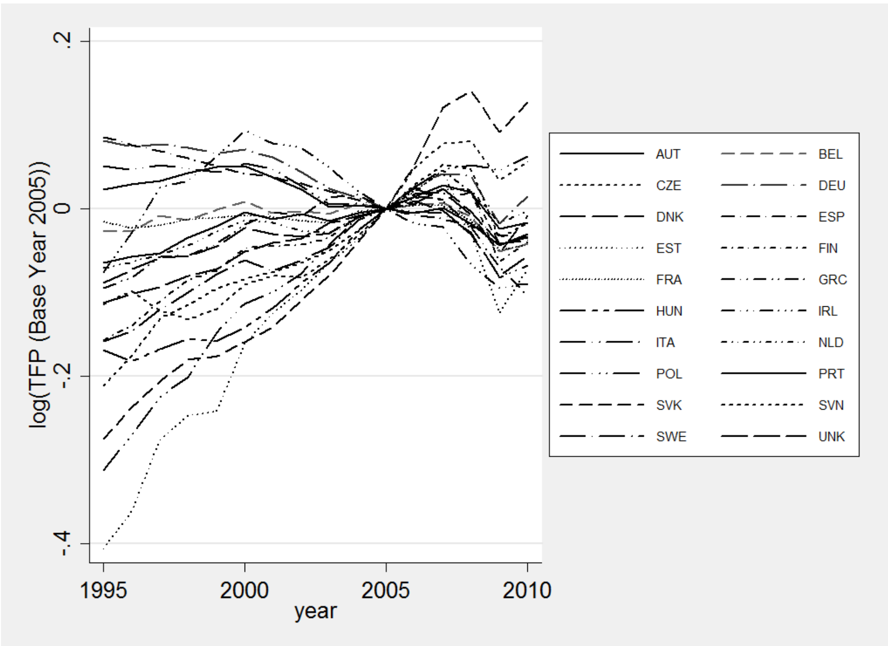

Figure 6: Log(Total Factor Productivity: Base Year = 2005)

Table A1: OECD Technology Intensity Classification

High-technology industries	Medium-high-technology industries
Aircraft and spacecraft	Electrical machinery and apparatus
Pharmaceuticals	Motor vehicles, trailers and semi-trailers
Office, accounting and computing machinery	Chemicals excluding pharmaceuticals
Radio, TV and communications equipment	Railroad equipment and transport equipment
Medical, precision and optical instruments	Machinery and equipment
Medium-low-technology industries	**Low-technology industries**
Building and repairing of ships and boats	Manufacturing; Recycling
Rubber and plastics products	Wood, pulp, paper, paper products, printing & publishing
Coke, refined petroleum products & nuclear fuel	Food products, beverages and tobacco
Other non-metallic mineral products	Textiles, textile products, leather and footwear
Basic metals and fabricated metal products	

Source: http://www.oecd.org/science/inno/48350231.pdf

Note: Only medium-high and high-tech industries used in the analysis for international trade

Table A2: Advantages and Disadvantages of Different Proxies for Quality of Human Capital

Proxies	Advantages	Disadvantages/limitations
TIMMS, PISA, PIAAC	Comprehensive test that includes many countries Many students examined at a time Homogenous test provides comparable results	Periodical tests hence not available , for long time periods
International Mathematical Olympiad (IMO)	Available for many countries Available for long time periods Homogenous test provides comparable results	Only six students assessed per country Specific to mathematics
Journal Publications	Provides good approximation for the final output of the education system Not specific to particular field of study Available through various sources	Nationality of the authors is not available, therefore it is impossible to connect the publications based on author-origin Only provides output of the researchers
Patents	Patents cover a broad range of technologies Available from many different sources, both in aggregated and disaggregated forms Data is available for almost all countries for long period of time	Not all inventions are patented. Some technical fields are more likely to patent than others. Moreover, non-technical fields rarely patent Processes innovations are very important but are rarely patented

Note: Patents- OECD Compendium of Patent Statistics 2008

Table A3a: Variance Inflation Factors for Main Models (Per capita variables)

Variable	Model(1)	Model(5a)
Log(R&D)	1.024	1.033
ImportSpill	1.037	1.037
Log(HCQ)	1.018	1.091
Log(FDI	1.015	1.059
Log(Gap)		1.086

Table A3b: Variance Inflation Factors for Main Models (Absolute variables)

Variable	Model(1)	Model(5a)
Log(R&D$_{abs}$)	1.048038	1.025591
ImportSpill$_{abs}$	1.320807	1.171094
Log(HCQ$_{abs}$)	1.368182	1.187920
Log(FDI$_{abs}$)	1.018674	1.049437
Log(Gap)		1.032596

Table A4: Cointegration Tests: Detailed

	Model(1)	Model(2)	Model(3)	Model(4)	Model(5a)	Model(5b)	Model(5c)
Within Dimension							
Panel v-Statistic	-0.36	-2.4	-3.69	-4.47	-1.28	-2.04	-0.61
Panel rho-Statistic	3.78	4.77	5.67	5.98	4.5	6.5	5.07
Panel PP-Statistic	3.715	-1.57*	-3.33***	-8.38***	-0.03	-2.33***	-7.41***
Panel ADF-Statistic	-2.69**	-4.59***	-5.69***	-4.63***	3.52***	-3.33***	-4.49***
Weighted- Panel v-Statistic	-1.72	-4.02	-3.17	-5.43	-2.88	-5.77	-5.15
Weighted-Panel rho-Statistic	1.74	3.81	4.86	6.01	3.48	5.43	4.98
Weighted-Panel PP-Statistic	-1.84**	-7.65***	-7.69***	-13.2***	-3.77***	-14.73***	-11.89***
Weighted-Panel ADF-Statistic	-4.62***	-7.47***	-7.21***	-5.92***	-2.14**	-4.06***	-4.38***
Between Dimension							
Group rho-Statistic	3.73	5.63	6.41	7.55	5.72	7.23	6.74
Group PP-Statistic	-0.17	-10.82***	-14.68***	-20.17***	-2.88***	-20.35***	-17.38***
Group ADF-Statistic	-3.33***	-5.96***	-7.39***	-7.12***	-1.61*	-5.79***	-5.88***
Kao Residual Cointegration Test	-1.94**	-2.43***	-3.66***	-4.24***	-2.26**	-2.91***	-2.92***

Table A5: Estimation Results: Absolute Variables

	Model(1)	Model(2)	Model(3)	Model(4)	Model(5a)	Model(5b)	Model(5c)
Log(R&D$_{abs}$)	0.214***	0.115***	0.207***	0.136***	0.127***	0.144***	0.147***
	(0.029)	(0.025)	(0.020)	(0.024)	(0.023)	(0.021)	(0.024)
ImportSpill$_{abs}$	0.055***	0.063***	-0.124***	0.023	0.059***	0.059***	0.064***
	(0.006)	(0.007)	(0.029)	(0.049)	(0.006)	(0.009)	(0.006)
Log(HCQ*Pop$_{abs}$)		0.119*	0.123*	0.062	0.113*	0.204***	0.098+
		(0.059)	(0.052)	(0.047)	(0.056)	(0.055)	(0.057)
Log(FDI$_{abs}$)		0.05***	0.021***	0.013	0.049***	0.051***	0.054***
		(0.005)	(0.006)	(0.053)	(0.005)	(0.005)	(0.006)
Log(FDI$_{abs}$)* Log(HCQ*Pop$_{abs}$)				0.001			
				(0.002)			
ImportSpill$_{abs}$* Log(HCQ*Pop$_{abs}$)				0.001			
				(0.002)			
Log(FDI$_{abs}$)* ImportSpill$_{abs}$			0.017***				
			(0.003)				
logGap					-0.005	0.007	0.016
					(0.012)	(0.027)	(0.125)
Log(FDI$_{abs}$)*logGap							-0.002
							(0.009)
ImportSpill$_{abs}$*logGap						0.009	
						(0.017)	
R^2	0.917	0.962	0.977	0.975	0.968	0.976	0.975
Adj-R^2	0.898	0.953	0.972	0.970	0.960	0.971	0.969
No of Observations	300	300	300	300	300	300	300
Pedroni Cointegration Test	4 out of 11	5 out of 11	6 out of 11	6 out of 11	5 out of 11	6 out of 11	6 out of 11
Kao Cointegration Test	-2.26**	-2.72***	-2.78***	-3.78***	-2.59***	-2.60***	-2.57***

Dependent variable is log(TFP). *p¡0.10 **p¡0.05 ***p¡0.01
Null hypothesis for cointegration test is no cointegration
Pedroni test results presented above are number of significant test results (at 10%) out of 11

Correlation Tables

Table A6a: Correlation Table (Per capita variables)

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
(i) Log(TFP)	1.000					
	——					
(ii) Log(R&D)	0.129	1.000				
	(0.020)	——				
(iii) ImportSpill	-0.264	-0.323	1.000			
	(0.000)	(0.000)	——			
(iv) Log(HCQ)	0.258	0.466	-0.721	1.000		
	(0.000)	(0.000)	(0.000)	——		
(v) Log(FDI)	0.495	0.435	-0.084	0.221	1.000	
	(0.000)	(0.000)	(0.129)	(0.000)	——	
(vi) Log(Gap)	0.034	-0.255	0.341	-0.584	-0.232	1.000
	(0.544)	(0.000)	(0.000)	(0.000)	(0.000)	——

Note: p-values in parenthesis

Table A6b: Correlation Table (Absolute Variables)

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
(i) Log(TFP)	1.000					
	——					
(ii) Log(R&D$_{abs}$)	0.269	1.000				
	(0.000)	——				
(iii) ImportSpill$_{abs}$	-0.036	-0.185	1.000			
	(0.518)	(0.001)	——			
(iv) Log(HCQ$_{abs}$)	0.291	0.763	-0.444	1.000		
	(0.000)	(0.000)	(0.000)	——		
(v) Log(FDI$_{abs}$)	0.571	0.673	-0.261	0.761	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	——	
(vi) Log(Gap)	0.034	-0.412	0.351	-0.519	-0.452	1.000
	(0.544)	(0.000)	(0.000)	(0.000)	(0.000)	——

Note: p-values in parenthesis

Descriptive Statistics

Table A7: Descriptive Statistics (Absolute Variables)

	Log(R&D$_{abs}$)	ImportSpill$_{abs}$	Log(HCQ$_{abs}$)	Log(FDI$_{abs}$)
Mean	10.200	1.424	27.918	11.217
Median	10.434	1.207	27.536	11.421
Maximum	14.153	3.302	32.670	14.036
Minimum	4.097	0.000	21.565	6.512
Std. Dev.	2.120	0.741	2.529	1.608
Skewness	-0.553	0.925	-0.166	-0.475
Kurtosis	2.713	2.849	2.783	2.746
Jarque-Bera	17.432	45.995	2.109	12.908
Probability	0.000	0.000	0.348	0.002
Observations	320	320	320	320