KOÇ UNIVERSITY-TÜSİAD ECONOMIC RESEARCH FORUM
WORKING PAPER SERIES

DIFFUSION OF TECHNOLOGY: CONVERGENCE IMPLICATIONS OF FDI

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Working Paper 1407
April 2014

KOÇ UNIVERSITY-TÜSİAD ECONOMIC RESEARCH FORUM
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Diffusion of Technology and Convergence of Income among Countries

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(Preliminary version; April 9, 2014)

Abstract

Theoretical models of growth reveal that either exogenous or endogenous, technology is the main driving force behind the long-run economic growth. Furthermore, in the endogenous growth framework, diffusion of technology is the basic mechanism of per capita income convergence among countries. This paper analyzes the per capita income convergence implications of foreign direct investment (FDI), considering that the latter is an international technology diffusion channel. Although FDI appears to be an important channel in the diffusion of technology models theoretically, empirical evidence related to the effect of FDI on growth is ambiguous. By applying the approach of Ben-David (1996), which focuses on convergence among countries grouped with respect to their mutual trade, this paper presents evidence that per capita income convergence exists among FDI home and host countries using three different convergence measures. The relatively higher speed of convergence prevailed among countries linked by FDI justifies the technological spillovers accompanied by FDI and provides evidence that FDI inflow is a mechanism of per capita income convergence among countries by allowing the diffusion of technology.

Key words: Economic Growth; FDI; Economic Integration; Technology Diffusion; Income Convergence
JEL codes:: O47, O33, F43, F15, F21

1 Introduction

Theoretical models of growth reveal that either exogenous or endogenous, technology is the main driving force behind the long-run economic growth. On one side, neoclassical models based on Solow (1956), hold that technology is available everywhere to everyone at no cost. At the other extreme, the endogenous growth theory, as it is first put forward by Romer (1990), relates a country's technical advances only to its own innovations. Therefore, the former implies absolute convergence of per capita incomes of countries whatever their respective characteristics are, while the latter has no convergence implications at all. Indeed, if technology diffusion were national in character, there would be no possibility for convergence. Each country would grow at a rate determined by its own research effort. But in reality, research in one country benefits from knowledge created in others, providing a mechanism by which a laggard country would tend to

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catch up, formulated by the diffusion of technology models of endogenous growth theory. Strong diffusion is the only force towards convergence, because it equalizes differences in technology across countries (Keller, 2001). In a typical model of technology diffusion, the rate of economic growth of a backward country depends on the extent of the adoption and implementation of new technologies that are already in use in leading countries. The reason is that almost the entire R&D activity in the world economy is concentrated in a small handful of industrial countries and, yet, not all of the other countries stagnate relative to the frontier.

Whether there is a per capita income convergence or divergence among countries has been searched for empirically as well. Income divergence, or at best, non-convergence, appears to characterize the behavior of most cross-country income differentials. Nevertheless, there has been some evidence of a higher convergence within the wealthier countries (e.g. 20 relatively advanced OECD countries), especially during the postwar period. This motivates researchers to focus on groups of countries with the aim of finding a relationship between per capita income convergence and international economic relations. An example of such studies, which analyzes the issue from the perspective of trade's contribution to the process, is Ben-David (1996). The idea is that if trade plays a role in the convergence process, it should probably be evident among countries that are the principal trade partners of one another. His results indicate that most of the groups created with respect to trade partnership exhibit income convergence. Convergence of his magnitude is not a common outcome among countries when they are grouped randomly. In an extension paper, Ben-David and Kimhi (2000) generalize the findings of Ben-David (1996) by including poorer countries in the analysis. Changes in the extent of trade appear to have an effect on the degree of income disparity among countries, such that increases in intra-group trade intensify the speed of convergence among the group members. Inspired by these two papers, which find that grouping countries according to their main trade affiliations tends to produce significant income convergence within groups, this paper tries to analyze convergence among FDI partners.

The new theory of economic growth underlines not only international trade, but also FDI, as a transmission mechanism that links a country's growth rate to economic developments in its partners (Grossman and Helpman, 1994). This implies that technology diffuses among countries through international trade and FDI. In general, empirical studies on international technology diffusion find evidence that there is significant cross-country technology diffusion via international trade channel. However evidence related to foreign direct investment as a technology diffusion mechanism is not that strong. Taking into account the ambiguity in evidence, this study tries to shed further light on FDI as a technology diffusion mechanism. Specifically, this study analyzes the the convergence of per capita income in a group of countries, following the strategy used in Ben-David (1996), but by focusing on groups constructed based on FDI instead of trade partnership. Each group consists of one of the top ten countries that account for the the outward direct investment stock worldwide and a set of host countries, towards which each of these ten major home countries' FDI is directed to. Finally, in order to detect the per capita income convergence implications of FDI, each pool is analyzed using three different measures of convergence, namely β-convergence based on neoclassical growth model, the convergence based on technology diffusion model of endogenous growth theory, which is derived and termed as

μ-convergence in this paper, and σ-convergence obtained from the annual change in the coefficient of variation. Empirical results of this paper show that there exists per capita income convergence among FDI home and host countries. Furthermore, the estimated speeds of β- and σ-convergence for each pool exceed the corresponding speeds of convergence between all involved countries except for the Spain pool, for which country fixed effects prevail. Although the μ-convergence based on the diffusion of technology models does not allow for such comparisons by construction, the estimated values are quite high.

The literature on international technology diffusion mainly investigates international technology spillovers and their effects either on growth directly or on total factor productivity (TFP) the component of output growth that is not attributable to the accumulation of inputs. Most of the empirical studies on international technology diffusion relies on a specific transmission channel to reveal the effect of foreign R&D on a country's total factor productivity. International trade is the most preferred one, where each of the foreign country's R&D is weighted with the import share of that country (Coe and Helpman, 1995 ; Coe, Helpman, and Hoffmaister, 1997; Nadiri and Kim, 1996; Gera, Gu, and Lee, 1999). According to this specification, the more a country imports from a foreign country, the more R&D spillover benefits accrue to that country. Coe and Helpman (1995) study whether a country's productivity is increasing in the extent to which it imports from high knowledge countries. They also investigate, for a given composition of imports whether a country's productivity is higher the higher is its overall import share. Their regression results suggest that there is support for both predictions. The authors conclude that not only does a country's total factor productivity depend on its own R&D capital stock, but also on the R&D capital stocks of its trade partners.

Unlike the robustness of empirical evidence supporting the international trade channel, the result of empirical studies on FDI as a technology diffusion mechanism among countries is ambiguous. Lichtenberg and van Pottelsberghe de la Potterie (1996) extend Coe and Helpmans (1995) analysis for a sample comprised by the 13 OECD countries, which have the relevant FDI data over the period 1971-90. Their empirical results show that outward FDI flows and import flows are two simultaneous channels through which technology is internationally diffused. Unlike the widespread belief, not inward FDI, but outward FDI is found to carry knowledge spillovers. The rationale behind outward FDI as a technology transfer mechanism is that the technological endowment accumulated by leaders is likely to be accessible to the foreign companies, which set up production and research facilities inside the technological leaders' boundaries.

Barrel and Pain (1997) investigate the role of FDI in the diffusion and assimilation of technologies and ideas across borders, specifically in Europe. Their main interest lies in the extent to which technology transfers and other spillovers from foreign-owned firms affect the pace of technical change and hence economic growth. So, they assume that technical progress is dependent on the aggregate level of foreign-owned assets together with an exogenous element proxied by a linear time trend. This assumption implies that technical progress will grow at a constant rate if direct investment grows at a constant rate. Assuming further that the FDI stock enters with a four quarter lag and using a two-factor constant elasticity of substitution (CES) production function with labor augmenting technical progress; they obtain significant effects from inward FDI for the United Kingdom and Germany. Extending the scope of the model in Barrel and Pain (1997) to obtain a panel data analysis of the impact of the economy-wide inward investment on technical change in four European countries -the United Kingdom, Germany, France, and the Netherlands-, Barrel and Pain (1999) present empirical evidence of significant spillovers on technical progress, thus important effects on the economic performance of host economies.

Choia (2004) finds that income level and growth gaps between source and host countries turn out to decrease as bilateral FDI increases between them using bilateral FDI data of OECD countries from 1982 to 1997. In other words, the level and growth of per capita income did converge as bilateral FDI flow increased between any two OECD countries. Using a panel data set covering 139 countries over the 1970 - 2009 period, Neto and Veiga (2013) empirically investigate the role of foreign direct investment on growth through diffusion of technology and innovation. Using an otherwise standard growth regression and regressions on productivity growth, they introduce the effect of foreign direct investment to capture the role of technological catch-up. The results show that FDI has a positive effect on productivity growth and on GDP growth.

In contrast to these findings, Haddad and Harrison (1993), reject the hypothesis that foreign presence accelerated productivity growth in domestic firms during the second half of the 1980s in the Moroccan manufacturing sector by employing a firm-level data set to test for such spillovers. Similarly, Aitken and Harrison (1999) find no evidence supporting the existence of technology spillovers from foreign firms to domestically owned firms using a panel of more than 4000 Venezuelan plants during 1976-1989.

The clue for these contradictory results can be found in Borensztein, de Gregorio, and Lee (1995), who examine empirically the role of FDI in the process of technology diffusion and economic growth in developing countries. They test the effect of FDI on economic growth in a framework of cross-country regressions utilizing data on FDI flows from industrial countries to 69 developing countries from 1970 to 1989. Their results suggest that FDI is an important vehicle for the transfer of technology, contributing to growth in larger measure than domestic investment. However, FDI is more productive than domestic investment only when the host country has a minimum threshold stock of human capital. Bijsterbosch and Kolasa (2009) affirm the importance of human capital on the effect of FDI on convergence of productivity in the central and eastern Europe towards that of the euro area.

Linking the ambiguous nature of the evidence on foreign direct investment as a technology diffusion mechanism to poor quality of FDI data, Xu (2000), examines the technology diffusion effect of multinational corporations (MNCs) in a multi-country framework. Technology transfer intensity of MNC affiliates is measured by their spending on royalties and license fees as a share of their value added assuming that higher spending by the affiliates on technology transfer corresponds to greater technology diffusion to the host country. The data contain majority-owned affiliates of US MNCs in the manufacturing sector in 40 countries, half of which is developing countries. Not surprisingly, there is strong evidence of technology diffusion towards developed countries, but weak evidence of that towards developing ones. Xu (2000) links this to the fact that most developing countries fail to reach the minimum human capital threshold level in order to benefit from the technology transfer of US MNCs.

The strategy of checking the convergence of per capita income in groups of countries, which are FDI partners preferred in this paper avoids the quality and aggregation problems related to the R&D and TFP series mentioned in Keller (1998). There are other advantages of this strategy. First, the FDI data are of poor quality to use directly in a regression analysis. Even within the OECD, countries define FDI differently (Xu, 2000). Indeed, even when the FDI statistics are presented according to a standardized format for all OECD member countries, there are limitations in data comparability due to differences in FDI definitions. This is particularly hampered by the fact that reinvested earnings are not included in data for several countries (OECD, 2002). Second, in this framework, there is no need to take into account separately the determinants of growth such as high rule-of-law index, low government consumption, price stability, and political stability, which shape the investment environment of countries. The underlying reason is that countries, who are major FDI receivers, are already those who have favorable investment environment. Otherwise vast amounts of FDI would not have been directed towards them. Furthermore, determinants of FDI brought together in Karagozoglu (1991) overlap with determinants of growth related to the investment environment to a large extent.

The remainder of the paper is organized as follows. The next section presents the empirical methodology that is used to capture the per capita income convergence among countries. Section 3 describes the data used in the empirical analysis, and the way country groups are constructed. The main results are presented and robustness checks are discussed in Section 4 while Section 5 concludes.

2 Empirical Methodology

In order to answer the question whether there has been a per capita income convergence between the FDI home and the host countries, they are grouped to form a panel data set. The groups - or pools in the terminology of this paper - are constructed using a similar strategy followed in Ben-David (1996) to create trade groups. He compares convergence in groups of countries that trade mutually more with different country groupings that are selected randomly and checks whether the former exhibit more income convergence than do the latter. Indeed, if trade plays a role in the convergence process, it should probably be evident among countries that are the principal trade partners of one another. Excluding countries that are primarily oil producers, formerly communist ones or that had 1960 per capita incomes below 25 percent of that of the United States; he ends up with 25 countries. Then, he determines main trade partners for each of these 25 countries, and in this manner, creates trade groups. The usual practice in analyzing the impact of trade on the growth process is to combine imports and exports and examine their joint effect. However, in order to see if any difference exists between groups formed solely on the basis of exports and those formed solely on the basis of imports, Ben-David (1996) forms 3 types of groups based on exports, imports, and the union of these two, limiting the size of each group to fewer than ten countries.

In applying this strategy to FDI, the first step is to determine the countries that account for the substantial amount of FDI realized worldwide. Since the bulk of direct investment outflows are accounted for by a handful of countries (OECD, 2002), we ended up with ten home countries. Then, the host countries, towards which each of these ten home countries' FDI is directed to, are searched for. Here, again, its worth mentioning that a handful of countries comprise the majority of a home country's direct investment outflows. In this way, 10 different country pools that contain a home country and a set of host countries are constructed. The last step is to examine whether there exists a per capita income convergence between the countries in each of these ten pools. If exists, whether its speed exceeds the speed of convergence between all involved countries is also checked.

The per capita income convergence among countries in each pool is analyzed using three different methods. The first method is called β-convergence and is derived from the neoclassical growth model. The neoclassical growth model of Solow (1956) predicts absolute income convergence among countries, i.e. poorer countries grow faster than richer ones, due to the diminishing returns to capital. There has been some evidence of a higher convergence within the wealthier countries, especially during the postwar period and among regions of some countries. When the analysis is broadened to include a wider spectrum of countries, the convergence evidence seems to disappear entirely, even a divergence is observed. However, once determinants of growth, such as human capital, government policies, and other variables put forward by the endogenous growth literature are accounted for, there appears to be strong evidence of convergence among countries, which is termed as conditional convergence. In this framework, the average growth rate of per capita output, y, over an initial time 0 to any future time T is given by[1]

$$(1/T)log[y(T)/y(0)] = g + [(1 - e^{-\beta T})/T]log[y^*/y(0)] \tag{1}$$

The Equation (1) implies that the average per capita growth rate of output depends negatively on the ratio of y(0) to y* once the steady-state growth rate, g, the convergence speed, β, and the averaging interval, T, are held constant. In other words, the effect of initial position, y(0), is conditioned on the steady state position, y*, implying conditional convergence.

Alternatively, the average growth rate of per capita output, y, for country i, between any time t and a previous time t-T, where T is a time interval, e.g. in years, can be written as

$$(1/T)log(y_{i,t}/y_{i,t-T}) = a - [(1 - e^{-\beta T})/T]log(y_{i,t-T}) \tag{2}$$

where $a \equiv g+[(1-e^{-\beta T})/T]log(y_i^*)$ and $y_{i,t-T}$ is per capita income in country i at the beginning of the interval. Similarly, $y_{i,t}$ is per capita income in country i at the end of the interval, T is the length of the interval, and β is the speed of β-convergence, i.e. the catch up speed of the relatively poorer economy to the rich one in terms of the level of per capita income.

The first method used to detect per capita income convergence among FDI partners, i.e. β-convergence, is based on the neoclassical growth model, which has no foresight related to the effect of FDI on convergence[2], thus, can not address the main question of this study. It can only signal a form of conditional convergence in a group of countries, where FDI partnership is used to homogenize them. As Romer (2001) states, conditional convergence can also be interpreted differently. Within the neoclassical model with exogenously determined level of technology,

[1] Barro and Sala-i-Martin (1995) Chapter 2.

[2] Though not encountered in the literature, FDI can be considered as an auxiliary element of capital accumulation in the neoclassical growth framework.

which is identical among all countries, this finding can be interpreted as evidence of diminishing returns to physical capital or human capital. But it is also possible that the technology is lower in the country that starts at a lower level of development and grows faster as better technology diffuses there. Barro and Sala-i-Martin (1995) interpret their results of convergence among U.S. states, the prefectures of Japan, and the regions of eight European countries as consistent with the neoclassical growth model. However, they admit that the observed convergence effect is consistent with the models of technological diffusion. considering that these regions have roughly similar tastes, technologies, and political institutions.

In accordance with the purpose of this paper, which analyzes the interactions between foreign direct investment and growth, considering the former as an international technology diffusion channel, the second convergence method used is based on the diffusion of technology model of endogenous growth theory. In fact, convergence implications of diffusion of technology models is more convincing theoretically considering that per capita income of countries converge each other as technology diffuses from a technologically more advanced country to a comparatively less advanced one. In the literature on international technology diffusion, technological knowledge is typically the design of a new intermediate product. According to this mechanism, technology diffuses internationally through foreign intermediate goods. The idea is that employing the foreign intermediate good involves the implicit usage of the design knowledge that was created with the R&D investment of the foreign inventor. In this case, the technological knowledge of the design is embodied in the intermediate good. As long as the intermediate good costs less than its opportunity costs -including the R&D costs of product development- there is a gain from having access to foreign intermediate goods. Therefore, improvements in technology have been the main source behind the economic growth, thus diffusion of technology is the basic mechanism of per capita income convergence among countries.

Technology diffusion mechanism from developed to less developed countries, which, has less, if not none at all, R&D activity, is modeled in Barro and Sala-i-Martin (1995). The main idea behind the model, which is called leader-follower model, is that if the diffusion of technology occurs gradually, then the follower countries tend to catch up to the leaders because imitation and implementation of discoveries are cheaper than innovation. The relationship between the growth rates of the follower and the leader countries is then derived as[3]

$$\gamma_i \approx \gamma_1 - \mu log[(y_i/y_1)/(y_i/y_1)^*], \tag{3}$$

where γ_i and γ_1 are per capita growth rates in follower countries and the leader country, respectively, μ is the speed of convergence in the diffusion of technology model framework, y_i and y_1 are per capita incomes of follower countries and the leader country, respectively, and finally $(y_i/y_1)^*$ is the steady-state ratio of per capita incomes in follower countries and the leader country. Since the role of FDI as a technology diffusion mechanism is focused in this study, the leader country is considered as the FDI home, whereas the follower one as the FDI host country and the convergence obtained in this framework is called as μ-convergence.

The final method used to detect convergence among FDI partners is σ-convergence, which

[3]The analysis of convergence based on diffusion of technology model is taken from Barro and Sala-i-Martin (1995) Chapter 8.

concerns cross-sectional dispersion of per capita income. In this context, convergence occurs if the dispersion measured for example, by the standard deviation of the logarithm of per capita income or product across a group of countries or regions declines over time (Barro and Sala-i-Martin, 1995). In this study, σ-convergence is measured by the coefficient of variation, which is obtained by dividing the standard deviation of the logarithm of real GDP per capita in constant price across the countries in each pool by the mean of the pool for each year.

Among the three methods mentioned above, the convergence termed in this paper as μ-convergence is the empirical method that fits most to the main focus of this study: whether there has been a per capita income convergence between FDI home and host countries, in other words whether the countries that attract relatively higher FDI from a particular country catch up with that country in terms of per capita income. The other methods can only detect whether there has been a per capita income convergence among a group of countries formed by an FDI home country and host countries towards which its FDI is mainly directed and are used mainly for the robustness check. They are also used to check whether the speed of convergence in each pool exceeds the speed of convergence between all involved countries, because the preferred econometric specification (3) does not allow to obtain the speed of convergence between all involved countries since an FDI home country cannot be identified in this case.

Considering that the number of countries in each pool is around 10, the results of the econometric analysis would be hardly reliable if the econometric specification (2) and (3) were directly used in regressions. In order to increment the number of observations, therefore, these two specifications are converted to panel data framework following the procedure proposed in Lall and Yilmaz (2001).

2.1 β-convergence

Assigning value 1 to the time period T in Equation (2) in order to have a panel data framework and rearranging, we end up with the following basic econometric specification, which is used to test β-convergence based on neoclassical growth model.

$$\log(y_{i,t}) = a + blog(y_{i,t-1}), \tag{4}$$

where the estimated b needs to be translated into speed of β-convergence using the formula:

$$\beta = -ln(b). \tag{5}$$

2.2 μ-convergence

Following the relationship between the growth rates of the follower countries and the leader country in the diffusion of technology framework, given in Equation (3), the average growth rate of the FDI host country i between initial time t-T and time t can be written as

$$(1/T)log(y_{i,t}/y_{i,t-T}) = (1/T)log(y_{1,t}/y_{1,t-T}) - \mu[log(y_{i,t}/y_{1,t})] + \mu[log(y_i/y_1)^*], \tag{6}$$

where $y_{i,t-T}$ and $y_{1,t-T}$ are per capita income in each of the FDI host country i and that in the

FDI home, respectively, at the beginning of interval. Similarly, $y_{i,t}$ and $y_{1,t}$ are per capita incomes at the end of the interval, T is the length of the interval, and μ is the speed of convergence, i.e. the catch up speed of the relatively poorer economy the rich one in terms of the level of per capita income in the diffusion of technology framework of endogenous growth theory. Since the steady-state ratio of per capita incomes in the FDI host and home countries, i.e. $log(y_i/y_1)^*$ is constant, the Equation (6) can be written as

$$(1/T)log(y_{i,t}/y_{i,t-T}) = a' + (1/T)log(y_{1,t}/y_{1,t-T}) - \mu[log(y_{i,t}/y_{1,t})], \tag{7}$$

where $a' = \mu[log(y_i/y_1)^*]$.

Similar to the procedure followed for the Equation (2) based on the neoclassical growth model, the Equation (7) can be converted to panel data framework by assigning value 1 to the time period T.

$$log(y_{i,t}/y_{i,t-1}) = a' + log(y_{1,t}/y_{1,t-1}) - \mu[log(y_{i,t}/y_{1,t})], \tag{8}$$

$$(1+\mu)[log(y_{i,t}) - log(y_{1,t})] = a' + [log(y_{i,t-1}) - log(y_{1,t-1})], \tag{9}$$

$$log(y_{i,t}/y_{1,t}) = a' + b'log(y_{i,t-1}/y_{1,t-1}), \tag{10}$$

where the estimated b' needs to be translated into speed of μ-convergence using the formula:

$$\mu = (1/b') - 1, \tag{11}$$

In the specification (10), the dependent variable is obtained by taking the log of what is obtained after dividing the per capita income of the FDI host countries i, by that of the home country 1, in each country pool. The μ-convergence obtained by regressing the log of the lagged value of the ratio of the per capita income of host to home countries on log of its current value shows the host countries' speed of converge towards the home country.

2.3 σ-convergence

The σ-convergence concerns cross-sectional dispersion of per capita income. In this context, convergence occurs if the dispersion measured for example, by the standard deviation of the logarithm of per capita income or product across a group of countries or regions declines over time (Barro and Sala-i-Martin, 1995).

In this paper, the dispersion is measured by the coefficient of variation (C_v), which is obtained by dividing the standard deviation of the logarithm of real GDP per capita in constant price (RGDPC) across the countries in each pool by the mean of the pool for each year following Ray (1998), so that only relative RGDPC matters. Formally,

$$C_v(log(RGDPC)) = (1/\overline{log(RGDPC_j)})[\sum_{j=1}^{m}(1/m)(log(RGDPC_j) - \overline{log(RGDPC_j)})^2]^{1/2}, \tag{12}$$

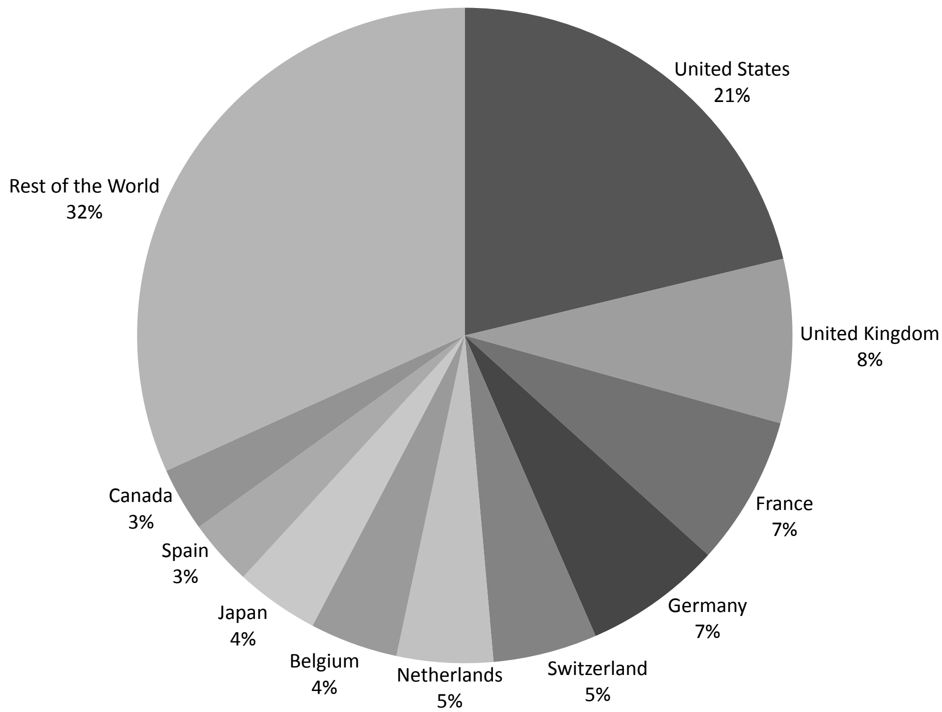

Figure 1: Direct Investment Abroad: Outward Position at the end of 2010

where $\overline{log(RGDPC_j)}$ is the mean of the logarithm of RGDPC in a pool and m is the number of countries in that pool.

The σ-convergence values are found by calculating the average annual change in $C_v(log(RGDPC))$ for each pool between the beginning and the end of the time period using the equation below:

$$\sigma = -((C_v(log(RGDPC))_t / C_v(log(RGDPC))_{t-T})^{1/T} - 1) \quad (13)$$

3 Data Set and the Construction of the Country Groups

The Foreign Direct Investment (FDI) data are taken from "International Direct Investment Statistics" database of OECD iLibrary. For the first step, i.e. in order to determine the countries that accounted for the bulk of direct investment abroad, "Outward position at year-end data for 2010" of the table "Foreign direct investment: main aggregates" is used. This data contains the whole outward FDI stock of each OECD member by the end of year 2010. The countries which have an outward FDI stock of over USD 500 billion and their share in world total FDI stock are given in Figure 1.

In accordance with Figure 1, the countries that account for the majority of FDI realized worldwide are determined as the United States, the United Kingdom, France, Germany, Switzer-

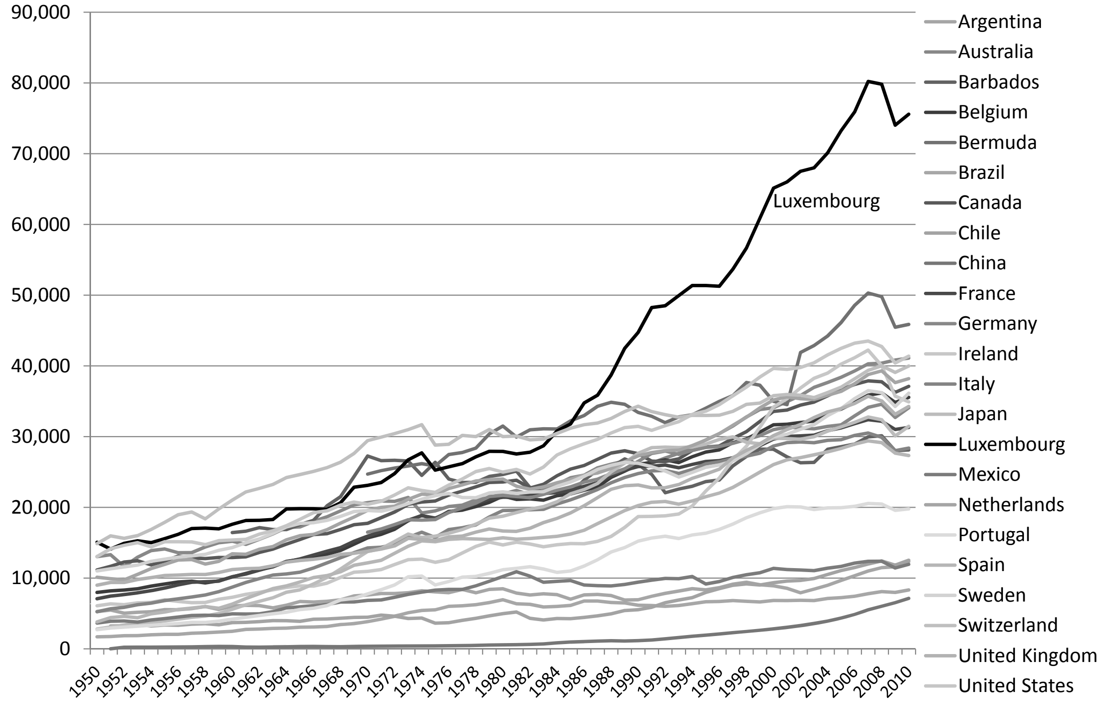

Figure 2: GDP per capita of countries for the 1950-2010

land, Netherlands, Belgium, Japan, Spain, and Canada, in the order of stock amount of direct investment abroad as of end 2010. For each of these ten countries a pool is created that consists of the home country itself and the main host countries towards which the home country's FDI is directed. During the second step, while determining the host countries, towards which each of these major home countries' FDI is directed, the 2010 data of the country tables named "Foreign Direct Investment Positions by partner country" in OECD iLibrary is used.

Per capita income data of the countries are taken from the "Penn World Table Version 7.1" (PWT 7.1) by Alan Heston, Robert Summers and Bettina Aten from "Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania" issued in November 2012. The data cover the years 1950-2010, so the empirical analysis is done for this time period. Among the various data presented in PWT 7.1, real GDP per capita (RGDPC) in constant price (Laspeyres) for each country is used in this paper.

Following the methodology in Ben-David (1996), a general criterion that limits the size of each group around ten countries is implemented. In general, a host country is eligible for the home country's pool if it accounts for at least 3 percent share in home countrys direct investment stock as of end 2010. The number of members in each group constructed using a 3 percent threshold ranged between 12 and 6, for Spain pool and Canada pools, respectively. An attempt to use a different threshold level for a particular group, e.g. 4 percent for Spain group in order to restrict the number of members below or equal to 10, changes the speed of convergence for this group significantly, thus avoided. Data for Cayman Islands, which is eligible for the USA, Japan, and Canada pools, is excluded since GDP per capita is not available in PWT 7.1.

GDP per capita data of all countries included in this study are shown in Figure 2 for the 1950-2010 period. Luxembourg turns out to be an apparent outlier in this figure, thus excluded from all country pools in order not to bias the regressions. Bermuda and Barbados, which are found to be eligible for the U.S.A. and Canada pools, respectively are also excluded from the pools, being two small island countries that retain a population less than 500,000. Therefore, the country groups are determined as shown in Table 1.

Pools	No.	Countries
U.S.A. pool	9	Netherlands, UK, Canada, Ireland, Switzerland, Australia, Japan, Germany
U.K. pool	8	USA, Netherlands, France, Ireland, Belgium, Spain, Canada
France pool	9	USA, Belgium, UK, Netherlands, Germany, Switzerland, Italy, Spain
Germany pool	7	USA, UK, Netherlands, France, Belgium, Italy
Switzerland pool	7	USA, UK, Netherlands, Germany, Canada, France
Netherlands pool	9	USA, UK, Belgium, Switzerland, Germany, France, Canada, Italy
Belgium pool	9	Netherlands. France. USA, Germany, UK, Sweden, Spain, Ireland
Japan pool	7	USA, Netherlands, China, Australia, UK, Brazil
Spain pool	11	UK, Brazil, USA, Netherlands, Argentina, Mexico, Portugal, France, Switzerland, Chile
Canada pool	5	USA, UK, Ireland, Australia
All countries	20	Argentina, Australia, Belgium, Brazil, Canada, Chile, China, France, Germany, Ireland, Italy, Japan, Mexico, Netherlands, Portugal, Spain, Sweden, Switzerland, UK, USA

Table 1: List of countries in each pool

4 Results

As a first step, the econometric specification given in Equation (4) is extended to allow for regional effects by estimating different intercepts for each pool member, which is known as fixed effects model.

$$log(y_{i,t}) = a + blog(y_{i,t-1}) + dD_i. \tag{14}$$

The fixed effects model is an appropriate specification if the focus is on a specific set of N countries (Baltagi, 1995). The fixed effects can be combined with the intercept that is identical for all pool members to yield

$$log(y_{i,t}) = a' + blog(y_{i,t-1}) \tag{15}$$

where $a' = a + dD_i$. In order to check the validity of fixed effects, the regional effects part of Equation (14) is removed, so that the econometric specification becomes

$$log(y_{i,t}) = a + blog(y_{i,t-1}) \tag{16}$$

The validity of the fixed effects can be tested by performing an F-test (Baltagi, 1995). This is a Chow test with the restricted residual sums of squares (RRSS) being that of the pooled least squares without fixed effects (Specification 16) and the unrestricted residual sums of squares (URSS) being that of the pooled least squares with fixed effects (Specification 15). In this case,

$$F_0 = [(RRSS - URSS)/(N - 1)]/[URSS/(NT - N - K)] \sim F_{N-1,N(T-1)-K}, \tag{17}$$

where NT is number of total observations[4], N is the number of cross sections and finally K is the number of independent variables. If the F-score for a country pool is smaller than the critical value at 1 percent significance level, the null hypothesis that restricted and unrestricted specifications are the same cannot be rejected. Thus it is not necessary to use fixed effects estimation in the following regressions.

In fact, the fixed-effects regression in STATA gives an F-statistic which states whether it would make more sense to pool the data or run the fixed-effects regression. If fixed-effects estimation (Specification 15) is rewritten as

$$log(y_{i,t}) = a + blog(y_{i,t-1}) + u_i + e_{i,t} \tag{18}$$

STATA gives the F test that all $u_i = 0$ -which is equivalent to the null hypothesis that restricted and unrestricted specifications are the same- in order to check the validity of fixed effects. The null hypothesis that all $u_i = 0$ can not be rejected for any country group except for that of Spain and Japan. Therefore, it will not make more sense to run the fixed-effects regression for U.S.A., U.K., France, Germany, Netherlands, Switzerland, Belgium, and Canada pools.

Another option is to run between regression, which estimates using the cross-sectional information in the data considering that there are two kinds of information in a panel data, cross-sectional and time-series. Formally, if the model to be estimated is

$$y_{i,t} = a + bx_{i,t} + u_i + e_{i,t} \tag{19}$$

the between regression produces estimates by running OLS on

[4] Since the data is unbalanced instead of NT, total number of observations given in the estimation result will be used here.

$$\bar{y_i} = a + b\bar{x_i} + u_i + e_{i,t} \tag{20}$$

The between estimator is consistent when OLS on the pooled sample is consistent. If time-series dimension, T, is long enough, the between estimator is robust to classical measurement error in the $x_{i,t}$ variable (Johnston and Dinardo, 1997). The information thrown-away by the between estimator, i.e. time-series dimension of a panel data can be used to obtain the so-called within estimator[5], which is equivalent to fixed-effects estimator. Specifically, within estimator performs OLS on the equation:

$$y_{i,t} - \bar{y_i} = a + b[x_{i,t} - \bar{x_i}] + u_i + e_{i,t} \tag{21}$$

The fixed-effects estimation solves the omitted variables problems by "throwing away" some of the variance that contaminates either pooled least squares or the between estimator. However, as Johnston and Dinardo (1997) state, the cure can be worse than the disease in case of measurement error in explanatory variables. The reason is that, although there may be considerable variation in real per capita GDP across countries, there is typically much less variation in changes for a particular country across time such that the latter may represent solely measurement error. This suggests that measurement error can seriously bias fixed effects estimates.

Pools	Pooled least squares	Fixed effects	Between estimator	Random effects
U.S.A. pool	0.0199	0.0179	0.0278	0.0198
U.K. pool	0.0167	0.0158	0.0218	0.0167
France pool	0.0229	0.0233	0.0214	0.0229
Germany pool	0.0194	0.0195	0.0188	0.0194
Switzerland pool	0.0170	0.0174	0.0152	0.0170
Netherlands pool	0.0197	0.0199	0.0190	0.0197
Belgium pool	0.0173	0.0164	0.0217	0.0173
Japan pool	0.0090	0.0036	0.0104	0.0075
Spain pool	0.0082	0.0208	0.0018	0.0109
Canada pool	0.0078	0.0057	0.0188	0.0078
All countries	0.0094	0.0117	0.0086	0.0101

Table 2: The β-convergence values estimated for country pools in 1950-2010 period

Note: The corresponding regression results are given in Appendix I

Table 2 depicts the β-convergence values for country pools estimated using four different regression methods: pooled least squares, the fixed-effects (within estimator), the between estimator, and the random effects. The β-convergence values obtained using random effects do not differ from those estimated by pooled least squares to a great extent. The β-convergence values estimated with fixed effects range between 0.0036 and 0.0233 while those estimated using the between estimator range between 0.0018 and 0.0278. Hauk and Wacziarg (2004) test the effectiveness of current methodologies by using simulation methods to evaluate the bias prop-

[5]It is called the within estimator because it uses only the variation within each cross-section unit (Johnston and Dinardo, 1997).

erties of several estimators commonly used in empirical growth literature in order to suggest improvements to cross-country growth empirics. Their results suggest that using an OLS estimator applied to a single cross-section of variables averaged over time (the between estimator) performs best in terms of the extent of bias on each of the estimated coefficients. Furthermore, the between estimator well suits the aim of this study, in which the main focus is to reveal the per capita income convergence among the countries in each pool using the cross-sectional information in the panel data and not the time-series dimension used in fixed-effects estimation that is equivalent to within (country) regression. Therefore, the between regression will be taken into account for β-convergence in the remainder of the empirical analysis.

β-convergence	μ-convergence	σ-convergence
U.S.A. Pool (2.78)	U.S.A. Pool (2.97)	U.S.A. Pool (3.11)
U.K. Pool (2.18)	U.K. Pool (2.27)	Canada pool (2.33)
Belgium pool (2.17)	Belgium pool (2.24)	Belgium pool (2.21)
France pool (2.14)	France pool (2.17)	France pool (2.12)
Netherlands pool (1.90)	Netherlands pool (1.91)	U.K. Pool (2.09)
Germany pool (1.88)	Canada pool (1.87)	Netherlands pool (1.95)
Canada pool (1.88)	Japan pool (1.18)	Switzerland pool (1.84)
Switzerland pool (1.52)	Switzerland pool (1.05)	Germany pool (1.77)
Japan pool (1.04)	Germany pool (0.92)	Japan pool (1.45)
Spain pool (0.18)	Spain pool (0.25)	Spain pool (0.57)
All countries (0.86)		All countries (1.22)

Table 3: Country pools sorted descending with respect to the estimated annual convergence (percent)

Note 1: The corresponding regression results for μ-convergence are given in Appendix II.

Note 2: The cross-sectional dispersion of the log of real GDP per capita in each pool for each year and the average annual percent change of the dispersion during the entire period (-σ-convergence) in each pool are given in Appendix III.

The μ-convergence is also estimated using both fixed-effects and the between regression. Fixed-effects are found to be valid only for the Spain pool, so only between regression results will be taken into account in the comparative analysis results given in Table 3, where all convergence values are reported in percentage terms. In Table 3, country pools are sorted descending according to their estimated convergence values using the three different measures, namely β-, μ-, and σ-convergence based on neoclassical growth model, diffusion of technology model, and cross-sectional dispersion, respectively.

First, comparing β- and μ-convergence values given in Table 3 reveals that while the lowest convergence is estimated in the Spain pool, the first five pools, namely U.S.A.[6], U.K., Belgium, France, and Netherlands pools, are found to be the ones where the convergence is highest by the two measures. The similarity in the order of country groups sorted with respect to estimated β- and μ-convergence values can be considered as the robustness of the results. Although the ranking of Canada pool differs with respect the two measures, the estimated speed is almost the same for β- and μ-convergence, with 1.88 vs 1.87 percent, respectively. The results for U.S.A.,

[6]The estimated convergence value for the U.S.A. pool is as high as the one estimated as 0.025, which implies a conditional rate of convergence of 2.5 percent per year for U.S.A. states, Canadian provinces, Japanese prefectures, and regions of western European countries by Barro and Sala-i-Martin (1995).

U.K., Belgium, France, Netherlands, and Canada pools are consistent with the conventional speed of conditional convergence of 2 percent obtained in cross sectional studies surveyed in Hauk and Wacziarg (2004). Germany, Switzerland, and Japan pools not only have different rankings with respect to different measures, but also have lower convergence values. Especially, there is a quite high difference between estimated β- and μ-convergence values for Germany and Switzerland pools.

Following the methodology, the next step is to check whether its speed exceeds the speed of convergence between all involved countries. The estimated β-convergence values that range between 2.78 percent (for the U.S.A. pool) and 0.18 percent (for Spain pool) among the groups, are higher than the estimated β-convergence of 0.86 among all 20 countries involved in the analysis, except for the Spain pool. However, taking into account the fact that (country) fixed effects are valid for Spain pool and that the 2.1 percent of β-convergence found using fixed-effects estimation for Spain pool is higher than 1.17 percent found for the pool with all 20 countries, as shown in Table 2. Therefore, it is possible to deduct that β-convergence is a prevailing feature among FDI home and host countries, though in a varying degree. Similarly, the estimated μ-convergence values using between regression ranges between 2.97 percent and 0.25 percent, for the U.S.A. and Spain pools, respectively. However, as stated in Section 2, it is not possible to check whether the speed of μ-convergence in each pool exceeds the speed of convergence between all involved countries, since an FDI home country needed to estimate the μ-convergence can not be identified in the latter case.

Finally, the results of the analysis of the σ-convergence support the findings for those of β- and μ-convergence. The σ-convergence relates to the cross-sectional dispersion of per capita income in each pool. In this study, the dispersion is measured by the coefficient of variation, which is obtained by dividing the standard deviation of the logarithm of real GDP per capita in constant price (RGDPC) across the countries in each pool by the mean of the pool. The σ-convergence occurs if the dispersion across the countries in a pool declines over time. As it is apparent in Figure 3, the dispersion declines over time in all pools. In order to obtain a σ-convergence value similar to those of β- and μ-convergence, this paper proposes to calculate the average annual change in the dispersion of log of real GDP per capita in each pool between the beginning and the end of the time period. As stated σ-convergence occurs if the dispersion declines over time, i.e. if the obtained average annual change is negative. Therefore, σ-convergence is the negative of the average annual percent change in the dispersion. The σ-convergence values obtained in this way are, in general, similar to μ-convergence values. For example, for the U.S.A. pool μ-convergence and σ-convergence values are 2.97 pad 3.11 percent, respectively. The same values are 2.24 and 2.21 percent for Belgium; 2.17 and 2.12 for France; 2.27 and 2.09 for the U.K.; and 1.91 and 1.95 for the Netherlands pools. The values differ to some extent for Canada pool with 1.87 versus 2.33 percent; for Japan pool 1.18 versus 1.45; for Switzerland pool 1.05 versus 1.84; for Germany pool 0.92 versus 1.77, while σ-convergence in Spain pool is the lowest as it is the case for both β- and μ-convergence.

To sum up, Table 3 shows that there exists per capita income convergence among FDI home and host countries. Furthermore, in general, the speed of per capita income convergence in each pool exceeds the speed of convergence between all involved countries. As summarized

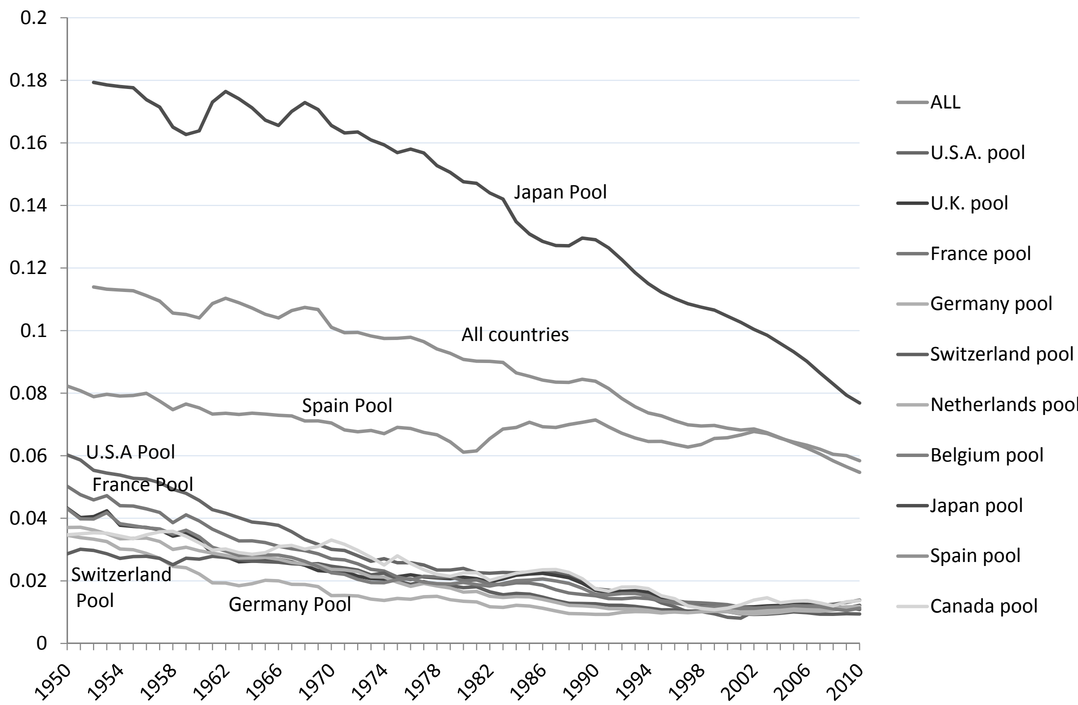

Figure 3: Dispersion of log of real GDP per capita across countries in each pool

in Table 3, only the speed of convergence in Spain pool fails to exceed the overall speed of convergence both in case of β- and σ-convergence. It is of no surprise considering that the convergence values given in Table 3 are obtained using the between estimator and that fixed effects are valid in the Spain pool.

5 Summary and Conclusions

As the central prediction of neoclassical growth theory that all countries would converge towards the same level of productivity proved to be an illusion and as the recent growth literature has highlighted the dependence of growth rates on the state of domestic technology relative to that of the rest of the world, one way for less developed countries to catch up is benefiting as much as possible from the technology diffusion. Strong diffusion has become the only force towards convergence, because it equalizes differences in technology across countries. In a typical model of technology diffusion, the rate of economic growth of a backward country depends on the extent of the adoption and implementation of new technologies that are already in use in leading countries.

International trade, i.e. importing and exporting, or FDI might help to stimulate technological diffusion, thus might help to explain the convergence that occurred between some countries during the last few decades in spite of the divergence observed globally since the mid 19th century. The empirical evidence supporting the international trade as a technology diffusion mechanism, which results in convergence among participating countries is rather strong. However, the convergence implications of empirical studies on FDI, which is a potentially equally important channel for the mediation of knowledge spillovers as international trade, is mixed. This study employs a different approach to investigate the interactions between technology diffusion and convergence of income among countries in order to provide a further insight regarding the growth effects of FDI.

Specifically, the main concern of this study is to answer the question whether there has been a per capita income convergence between countries that are FDI partners by pooling them to form a panel data set. Each pool consists of one of the top ten countries that account for the the outward direct investment stock worldwide and a set of host countries, towards which each of these ten major home countries' FDI is directed to. Finally, in order to detect the per capita income convergence implications of FDI, each pool is analyzed using three different measures of convergence, namely β-convergence based on neoclassical growth model, the convergence based on technology diffusion model of endogenous growth theory, which is termed as μ-convergence in this paper, and σ-convergence obtained from the annual change in the coefficient of variation.

The β-convergence implies that poorer economies tend to grow faster than wealthier ones due to diminishing returns to capital. The hypothesis that poor economies tend to grow faster per capita than rich ones -without conditioning on any other characteristics of economies- is referred to as absolute convergence (Barro and Sala-i-Martin, 1995). Considering that the econometric specification used for β-convergence has only the lagged values of per capita income as dependent variable, it seems this study deals with unconditional convergence. However, considering that β-convergence is estimated between the FDI home and host countries, the estimated values are in fact conditioned on FDI partnership, which is used to homogenize the economies.

First, to obtain β-convergence values, the basic econometric specification based on the neoclassical growth model is extended to allow for regional effects by estimating different intercepts for each pool member, which is known as fixed-effects model. The validity of fixed-effects is checked using the F-test proposed in Baltagi (1995), such that the restricted specification is the pooled least squares and the unrestricted specification is the fixed effects regression. The null hypothesis that restricted and unrestricted specifications are the same can not be rejected for country groups other than Spain and Japan pools. Therefore, it will not make more sense to run the fixed-effects regression for the U.S.A., U.K., France, Germany, Netherlands, Switzerland, Belgium, and Canada pools. The β-convergence values are also estimated using the between estimator and the random effects, besides fixed-effects and pooled least squares. Among all these specifications, the between estimator, which estimates using the cross-sectional information in the data is preferred considering that using cross-sectional not the time-series dimension of a panel data suits more to the main focus of this paper that tries to reveal the per capita income convergence among the countries. This selection is also supported by the literature, which states that the between estimator performs best in terms of the extent of bias on each of the estimated coefficients.(Hauk and Wacziarg, 2004). Excluding Spain and Japan pools, for which fixed effects are valid, the β-convergence values estimated using the between estimator range between

2.78 and 1.52 percent among the remaining eight pools. These results are consistent with the conventional speed of conditional convergence of 2 percent obtained in cross sectional studies surveyed in Hauk and Wacziarg (2004). Therefore, the β-convergence seems to be a prevailing feature among FDI home and host countries.

Secondly, though this paper aims to analyze the per capita income convergence implications of foreign direct investment in the endogenous growth framework considering the latter as an international technology diffusion channel, the basic econometric specification used to estimate convergence among FDI partners is based on the neoclassical growth model. In order to cope with this inconsistency, the relationship between the growth rates of the leader and the follower countries derived in Barro and Sala-i-Martin (1995) based on the diffusion of technology model of endogenous growth theory is used. This relationship is adapted to panel data framework and the convergence of per capita incomes of FDI host countries toward the FDI home country -termed as μ-convergence in this paper- is estimated. Excluding Spain pool for which fixed effects prevail, the estimated μ-convergence values using the between regression ranges between 2.97 percent and 0.92 percent, for U.S.A. and Germany pools, respectively. Furthermore, the order of country groups sorted with respect to estimated μ-convergence values are found similar to the β-convergence values obtained using the econometric specification derived from neoclassical growth model. In both specifications, the highest convergence values are obtained in the same order, for United States, United Kingdom, Belgium, France, and Netherlands pools while the lowest convergence value is estimated for the Spain pool. The similarity in the rankings of country pools sorted according to the convergence values estimated with different measures, which are based on different models, can be considered as the robustness of the results.

Finally, the results of the analysis of the σ-convergence support the findings for those of β- and μ-convergence. The σ-convergence relates to the cross-sectional dispersion of per capita income in each pool. In this study, the dispersion is measured by the coefficient of variation, which is obtained by dividing the standard deviation of the logarithm of real GDP per capita in constant price (RGDPC) across the countries in each pool by the mean of the pool. In order to obtain a σ-convergence value similar to those of β- and μ-convergence, this paper proposes to calculate the average annual percent change of the dispersion in each pool between the beginning and the end of the time period. The σ-convergence values obtained in this way are similar to μ-convergence values, especially for Belgium, France, and Netherlands pools.

Summing up, empirical results of this paper show that there exists per capita income convergence among FDI home and host countries. Furthermore, the estimated speeds of β- and σ-convergence for each pool exceed the corresponding speeds of convergence between all involved countries except for the Spain pool, for which country fixed effects prevail. Although the μ-convergence based on the diffusion of technology models does not allow such comparisons, the estimated values using the between regression range between 2.97 and 0.92 percent, for the U.S.A. and Germany pools, respectively. The relatively high speed of convergence prevailed among countries linked by FDI justifies the technological spillovers accompanied by FDI and provides evidence that the diffusion of technology is a mechanism of per capita income convergence among countries.

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Appendix I: The β-convergence estimated with different regression models

	(Pooled LS)	**(Fixed effects)**	**(Between estimator)**	**(Random effects)**
VARIABLE	lrgdpc	lrgdpc	lrgdpc	lrgdpc
U.S.A. pool				
lrgdpc_l1	0.98031***	0.98223***	0.97259***	0.98039***
	(-0.00258)	(-0.00287)	(-0.006)	(-0.00259)
Constant	0.21858***	0.19954***	0.29528***	0.21787***
	(-0.02563)	(-0.02855)	(-0.05961)	(-0.02574)
Observations	520	520	520	520
R-squared	0.99643	0.99565	0.99973	
Number of countries		9	9	9
U.K. pool				
lrgdpc_l1	0.98346***	0.98428***	0.97844***	0.98346***
	(-0.00252)	(-0.00273)	(-0.00326)	(-0.00252)
Constant	0.18690***	0.17882***	0.23623***	0.18690***
	(-0.02476)	(-0.02684)	(-0.03204)	(-0.02476)
Observations	480	480	480	480
R-squared	0.99688	0.99639	0.99993	
Number of countries		8	8	8
France pool				
lrgdpc_l1	0.97736***	0.97697***	0.97880***	0.97736***
	(-0.00224)	(-0.00253)	(-0.00237)	(-0.00224)
Constant	0.24738***	0.25120***	0.23307***	0.24738***
	(-0.02218)	(-0.02502)	(-0.02345)	(-0.02218)
Observations	520	520	520	520
R-squared	0.99729	0.9966	0.99996	
Number of countries		9	9	9
Germany pool				
lrgdpc_l1	0.98076***	0.98064***	0.98139***	0.98076***
	(-0.00249)	(-0.00267)	(-0.00375)	(-0.00249)
Constant	0.21342***	0.21456***	0.20718***	0.21342***
	(-0.0247)	(-0.02641)	(-0.03718)	(-0.0247)
Observations	400	400	400	400
R-squared	0.99743	0.99711	0.99993	
Number of countries		7	7	7
Switzerland pool				
lrgdpc_l1	0.98313***	0.98278***	0.98491***	0.98313***
	(-0.00293)	(-0.00322)	(-0.00289)	(-0.00293)
Constant	0.18919***	0.19272***	0.17141***	0.18919***
	(-0.02936)	(-0.0322)	(-0.0289)	(-0.02936)
Observations	400	400	400	400
R-squared	0.99647	0.99581	0.99996	
Number of countries		7	7	7

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix I: The β-convergence estimated with different regression models - continued

	(Pooled LS)	(Fixed effects)	(Between estimator)	(Random effects)
VARIABLE	lrgdpc	lrgdpc	lrgdpc	lrgdpc
Netherlands pool				
lrgdpc_l1	0.98046***	0.98031***	0.98122***	0.98046***
	(-0.00234)	(-0.00256)	(-0.00271)	(-0.00234)
Constant	0.21621***	0.21775***	0.20870***	0.21621***
	(-0.02324)	(-0.02547)	(-0.02699)	(-0.02324)
Observations	520	520	520	520
R-squared	0.99707	0.99653	0.99995	
Number of countries		9	9	9
Belgium pool				
lrgdpc_l1	0.98286***	0.98373***	0.97852***	0.98286***
	(-0.00241)	(-0.00265)	(-0.00279)	(-0.00241)
Constant	0.19262***	0.18413***	0.23541***	0.19262***
	(-0.02376)	(-0.02611)	(-0.02752)	(-0.02376)
Observations	520	520	520	520
R-squared	0.99689	0.99631	0.99994	
Number of countries		9	9	9
Japan pool				
lrgdpc_l1	0.99108***	0.99638***	0.98968***	0.99252***
	(-0.00148)	(-0.00323)	(-0.00276)	(-0.00211)
Constant	0.11223***	0.06328**	0.12520***	0.09891***
	(-0.01385)	(-0.02993)	(-0.02571)	(-0.01973)
Observations	418	418	418	418
R-squared	0.99907	0.9957	0.99996	
Number of countries		7	7	7
Spain Pool				
lrgdpc_l1	0.99182***	0.97946***	0.99819***	0.98916***
	(-0.00192)	(-0.00323)	(-0.00311)	(-0.00227)
Constant	0.10009***	0.21638***	0.04019	0.12510***
	(-0.01813)	(-0.03038)	(-0.02932)	(-0.02141)
Observations	659	659	659	659
R-squared	0.99754	0.99303	0.99991	
Number of countries		11	11	11
Canada Pool				
lrgdpc_l1	0.99223***	0.99437***	0.98141***	0.99223***
	(-0.00375)	(-0.00412)	(-0.00379)	(-0.00375)
Constant	0.09885***	0.07770*	0.20588**	0.09885***
	(-0.03716)	(-0.04079)	(-0.03754)	(-0.03716)
Observations	300	300	300	300
R-squared	0.99576	0.99498	0.99996	
Number of countries		5	5	5
All countries				
lrgdpc_l1	0.99067***	0.98837***	0.99145***	0.98994***
	(-0.00113)	(-0.00212)	(-0.0021)	(-0.00149)
Constant	0.11383***	0.13558***	0.10645***	0.12070***
	(-0.01068)	(-0.02003)	(-0.01988)	(-0.01419)
Observations	1,177	1,177	1,177	1,177
R-squared	0.99848	0.99472	0.99992	
Number of countries		20	20	20

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix II: The μ-convergence estimated with different regression models

	(Pooled LS)	(Fixed effects)	(Between estimator)	(Random effects)
VARIABLE	lrrgdp	lrrgdp	lrrgdp	lrrgdp
U.S.A. Pool				
lrrgdp_l1	0.96671***	0.96099***	0.97116***	0.96606***
	(-0.00485)	(-0.00727)	(-0.00752)	(-0.00517)
Constant	-0.00315*	-0.00448**	-0.00225	-0.00333*
	(-0.00179)	(-0.00219)	(-0.00235)	(-0.00198)
Observations	460	460	460	460
R-squared	0.98863	0.97487	0.99964	
Number of countries		8	8	8
U.K. Pool				
lrrgdp_l1	0.97021***	0.95470***	0.97783***	0.97021***
	(-0.00543)	(-0.00947)	(-0.00216)	(-0.00543)
Constant	0.00405***	0.00489***	0.00363***	0.00405***
	(-0.00136)	(-0.00142)	(-0.00045)	(-0.00136)
Observations	420	420	420	420
R-squared	0.98709	0.96102	0.99998	
Number of countries		7	7	7
France Pool				
lrrgdp_l1	0.97360***	0.95659***	0.97876***	0.97360***
	(-0.00393)	(-0.00812)	(-0.00287)	(-0.00393)
Constant	0.00098	0.00215*	0.00068	0.00098
	(-0.00103)	(-0.00113)	(-0.00065)	(-0.00103)
Observations	460	460	460	460
R-squared	0.99258	0.96851	0.99995	
Number of countries		8	8	8
Germany Pool				
lrrgdp_l1	0.98304***	0.94930***	0.99088***	0.98304***
	(-0.00975)	(-0.02243)	(-0.00893)	(-0.00975)
Constant	0.00057	0.00081	0.00051	0.00057
	(-0.00121)	(-0.00122)	(-0.001)	(-0.00121)
Observations	240	240	240	240
R-squared	0.97711	0.88492	0.99968	
Number of countries		6	6	6
Switzerland Pool				
lrrgdp_l1	0.98918***	0.98927***	0.98965***	0.98918***
	(-0.0072)	(-0.00869)	(-0.01039)	(-0.0072)
Constant	0.0025	0.00253	0.00292	0.0025
	(-0.00269)	(-0.00308)	(-0.00339)	(-0.00269)
Observations	340	340	340	340
R-squared	0.98242	0.97495	0.99956	
Number of countries		6	6	6

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix II: The μ-convergence estimated with different regression models - continued

	(Pooled LS)	(Fixed effects)	(Between estimator)	(Random effects)
VARIABLE	lrrgdp	lrrgdp	lrrgdp	lrrgdp
Netherlands Pool				
lrrgdp_l1	0.97299***	0.94845***	0.98121***	0.97299***
	(-0.00596)	(-0.01188)	(-0.00308)	(-0.00596)
Constant	-0.00137	-0.00285**	-0.00086	-0.00137
	(-0.00126)	(-0.0014)	(-0.00056)	(-0.00126)
Observations	460	460	460	460
R-squared	0.98313	0.93396	0.99994	
Number of countries		8	8	8
Belgium pool				
lrrgdp_l1	0.97355***	0.96221***	0.97813***	0.97355***
	(-0.0051)	(-0.00954)	(-0.00351)	(-0.0051)
Constant	-0.001	-0.00111	-0.00101	-0.001
	(-0.00115)	(-0.00116)	(-0.00065)	(-0.00115)
Observations	460	460	460	460
R-squared	0.98758	0.95757	0.99992	
Number of countries		8	8	8
Japan pool				
lrrgdp_l1	0.98748***	0.97891***	0.98838***	0.98748***
	(-0.00228)	(-0.00723)	(-0.00219)	(-0.00228)
Constant	-0.01802***	-0.02298***	-0.01746**	-0.01802***
	(-0.00343)	(-0.00525)	(-0.00319)	(-0.00343)
Observations	298	298	298	298
R-squared	0.99843	0.98432	0.99999	
Number of countries		5	5	5
Spain Pool				
lrrgdp_l1	0.99024***	0.94366***	0.99747***	0.99024***
	(-0.0027)	(-0.00708)	(-0.00272)	(-0.0027)
Constant	-0.01177***	-0.01781***	-0.01083***	-0.01177***
	(-0.00187)	(-0.00199)	(-0.00176)	(-0.00187)
Observations	599	599	599	599
R-squared	0.99558	0.96795	0.99994	
Number of countries		10	10	10
Canada Pool				
lrrgdp_l1	0.98106***	0.97969***	0.98165***	0.98106***
	(-0.0083)	(-0.01517)	(-0.00469)	(-0.0083)
Constant	0.00048	0.00034	0.00054	0.00048
	(-0.00223)	(-0.00258)	(-0.00108)	(-0.00223)
Observations	240	240	240	240
R-squared	0.98325	0.94665	0.99995	
Number of countries		4	4	4

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix III: The coefficient of variation of log per capita GDP for each year and the average annual percent change in the coefficient of variation for country pools

Year	U.S.A.	U.K.	France	Germany	Switzerland	Netherlands	Belgium	Japan	Spain	Canada	ALL
1950	0.0603	0.0432	0.0502	0.0346	0.0286	0.0371	0.0431		0.0823	0.0347	
1951	0.0587	0.0402	0.0475	0.0338	0.0301	0.0371	0.0398		0.0808	0.0350	
1952	0.0553	0.0406	0.0459	0.0333	0.0297	0.0362	0.0398	0.1793	0.0789	0.0354	0.1139
1953	0.0545	0.0424	0.0472	0.0326	0.0287	0.0351	0.0418	0.1785	0.0796	0.0352	0.1132
1954	0.0538	0.0378	0.0440	0.0302	0.0272	0.0335	0.0383	0.1780	0.0791	0.0344	0.1130
1955	0.0528	0.0374	0.0439	0.0300	0.0278	0.0336	0.0376	0.1776	0.0793	0.0335	0.1127
1956	0.0525	0.0371	0.0430	0.0288	0.0278	0.0337	0.0369	0.1738	0.0799	0.0347	0.1112
1957	0.0514	0.0363	0.0419	0.0272	0.0272	0.0326	0.0366	0.1715	0.0775	0.0357	0.1094
1958	0.0493	0.0343	0.0386	0.0246	0.0252	0.0301	0.0349	0.1650	0.0747	0.0358	0.1056
1959	0.0480	0.0352	0.0411	0.0242	0.0272	0.0307	0.0362	0.1627	0.0765	0.0342	0.1051
1960	0.0457	0.0328	0.0391	0.0222	0.0269	0.0296	0.0341	0.1638	0.0753	0.0327	0.1051
1961	0.0427	0.0288	0.0365	0.0194	0.0278	0.0289	0.0307	0.1730	0.0733	0.0298	0.1100
1962	0.0416	0.0278	0.0346	0.0193	0.0275	0.0281	0.0295	0.1764	0.0736	0.0304	0.1118
1963	0.0402	0.0261	0.0328	0.0184	0.0268	0.0273	0.0281	0.1741	0.0732	0.0301	0.1106
1964	0.0388	0.0263	0.0328	0.0191	0.0263	0.0273	0.0284	0.1712	0.0736	0.0303	0.1090
1965	0.0384	0.0265	0.0322	0.0202	0.0261	0.0275	0.0283	0.1673	0.0733	0.0307	0.1069
1966	0.0377	0.0269	0.0311	0.0200	0.0259	0.0269	0.0282	0.1656	0.0729	0.0330	0.1057
1967	0.0357	0.0261	0.0303	0.0189	0.0255	0.0259	0.0275	0.1700	0.0727	0.0320	0.1079
1968	0.0332	0.0249	0.0297	0.0188	0.0253	0.0254	0.0262	0.1729	0.0711	0.0302	0.1089
1969	0.0316	0.0233	0.0286	0.0181	0.0255	0.0250	0.0245	0.1707	0.0711	0.0290	0.1079
1970	0.0297	0.0230	0.0270	0.0153	0.0247	0.0237	0.0226	0.1656	0.0705	0.0283	0.1029
1971	0.0293	0.0230	0.0267	0.0154	0.0241	0.0235	0.0221	0.1632	0.0682	0.0281	0.1013
1972	0.0277	0.0215	0.0255	0.0152	0.0235	0.0229	0.0205	0.1635	0.0676	0.0266	0.1016
1973	0.0262	0.0207	0.0237	0.0141	0.0219	0.0213	0.0194	0.1609	0.0681	0.0254	0.1008
1974	0.0268	0.0205	0.0231	0.0137	0.0225	0.0212	0.0194	0.1594	0.0670	0.0238	0.1003
1975	0.0253	0.0213	0.0213	0.0144	0.0199	0.0196	0.0204	0.1569	0.0691	0.0252	0.1000
1976	0.0249	0.0219	0.0204	0.0141	0.0189	0.0182	0.0207	0.1580	0.0687	0.0257	0.1007
1977	0.0244	0.0213	0.0215	0.0149	0.0198	0.0192	0.0196	0.1568	0.0675	0.0243	0.0994
1978	0.0227	0.0209	0.0212	0.0150	0.0187	0.0184	0.0191	0.1527	0.0667	0.0232	0.0969
1979	0.0221	0.0207	0.0213	0.0140	0.0185	0.0177	0.0190	0.1506	0.0644	0.0224	0.0954
1980	0.0220	0.0212	0.0200	0.0135	0.0178	0.0164	0.0195	0.1476	0.0611	0.0233	0.0932
1981	0.0213	0.0207	0.0203	0.0133	0.0181	0.0166	0.0188	0.1471	0.0616	0.0233	0.0927
1982	0.0202	0.0196	0.0190	0.0117	0.0165	0.0151	0.0183	0.1440	0.0655	0.0217	0.0927
1983	0.0208	0.0206	0.0187	0.0115	0.0155	0.0147	0.0191	0.1421	0.0685	0.0235	0.0924
1984	0.0214	0.0218	0.0194	0.0122	0.0160	0.0150	0.0201	0.1348	0.0690	0.0250	0.0890
1985	0.0215	0.0222	0.0193	0.0120	0.0158	0.0149	0.0203	0.1309	0.0707	0.0257	0.0878
1986	0.0217	0.0224	0.0186	0.0113	0.0148	0.0141	0.0206	0.1285	0.0693	0.0262	0.0864
1987	0.0212	0.0218	0.0172	0.0104	0.0137	0.0131	0.0200	0.1272	0.0690	0.0262	0.0856
1988	0.0203	0.0210	0.0161	0.0095	0.0128	0.0122	0.0192	0.1271	0.0700	0.0252	0.0857
1989	0.0188	0.0193	0.0156	0.0095	0.0128	0.0120	0.0176	0.1296	0.0707	0.0229	0.0869
1990	0.0170	0.0170	0.0152	0.0093	0.0127	0.0117	0.0157	0.1290	0.0714	0.0194	0.0866
1991	0.0167	0.0163	0.0143	0.0093	0.0122	0.0111	0.0155	0.1264	0.0692	0.0186	0.0843
1992	0.0167	0.0167	0.0143	0.0099	0.0122	0.0111	0.0159	0.1227	0.0672	0.0193	0.0812
1993	0.0161	0.0169	0.0146	0.0102	0.0118	0.0110	0.0160	0.1185	0.0657	0.0194	0.0783
1994	0.0149	0.0163	0.0143	0.0101	0.0113	0.0106	0.0153	0.1150	0.0645	0.0185	0.0763
1995	0.0125	0.0146	0.0136	0.0097	0.0107	0.0099	0.0137	0.1123	0.0646	0.0156	0.0753
1996	0.0110	0.0137	0.0134	0.0101	0.0108	0.0100	0.0129	0.1103	0.0636	0.0139	0.0736
1997	0.0092	0.0130	0.0131	0.0102	0.0103	0.0098	0.0123	0.1086	0.0628	0.0117	0.0722
1998	0.0091	0.0124	0.0130	0.0105	0.0103	0.0101	0.0118	0.1075	0.0636	0.0109	0.0717
1999	0.0090	0.0123	0.0127	0.0111	0.0103	0.0103	0.0117	0.1066	0.0655	0.0101	0.0721
2000	0.0088	0.0122	0.0124	0.0109	0.0101	0.0101	0.0116	0.1046	0.0658	0.0093	0.0715
2001	0.0085	0.0116	0.0116	0.0103	0.0094	0.0095	0.0111	0.1027	0.0666	0.0084	0.0710
2002	0.0088	0.0117	0.0113	0.0102	0.0093	0.0094	0.0112	0.1004	0.0678	0.0080	0.0708
2003	0.0092	0.0120	0.0113	0.0106	0.0093	0.0096	0.0115	0.0985	0.0671	0.0078	0.0695
2004	0.0093	0.0122	0.0116	0.0110	0.0096	0.0099	0.0117	0.0959	0.0656	0.0078	0.0677
2005	0.0097	0.0125	0.0120	0.0115	0.0101	0.0105	0.0121	0.0932	0.0644	0.0081	0.0658
2006	0.0094	0.0125	0.0120	0.0113	0.0098	0.0104	0.0119	0.0902	0.0634	0.0081	0.0640
2007	0.0090	0.0124	0.0121	0.0112	0.0093	0.0103	0.0118	0.0865	0.0621	0.0076	0.0620
2008	0.0085	0.0118	0.0125	0.0114	0.0093	0.0106	0.0111	0.0829	0.0605	0.0071	0.0597
2009	0.0099	0.0113	0.0131	0.0116	0.0095	0.0112	0.0105	0.0794	0.0601	0.0084	0.0579
2010	0.0091	0.0122	0.0139	0.0119	0.0094	0.0114	0.0112	0.0769	0.0584	0.0084	0.0560
AAPC	-3.11	-2.09	-2.12	-1.77	-1.84	-1.95	-2.21	-1.45	-0.57	-2.33	-1.22

AAPC: Average Annual Percent Change