Cross-border Economic Activities, Human Capital and Efficiency: A Stochastic Frontier Analysis for OECD Countries

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Abstract

We study the growth effects of outward oriented economies by using stochastic frontier analysis to measure the efficiency externalities of three forms of economic cross-border activities – international trade, FDI and migration – for OECD countries. The study also examines whether the efficiency of these cross border activities is affected by the level of human capital in the host country. We find that international trade and FDI are important channels for improving efficiency, as is human capital accumulation, and that the positive effects of international trade, FDI, and migration depend crucially on the level of accumulated human capital. Our results show that the impact of human capital is important for increasing efficiency via international trade flows and FDI flows, while immigration into countries that are richer in human capital enhances their efficiency relatively more than immigration into countries with lower human capital. These results remain robust to alternate measures of human capital, controls on education levels among immigrants, and to a nonparametric estimation of the model.

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" 'Globalization' can mean something different to each of us, so let me specify what I have in mind: the increasing integration of economies in the world, particularly through the international flow of goods, services, and capital—and, increasingly, people (labor) and knowledge (technology and information)."

— Speech given by Saleh M. Nsouli, International Monetary Fund, July 2008

1. Introduction

As governments lowered their policy barriers to foreign countries in the 1980s and 1990s, the pace of globalization increased rapidly during this period. The World Bank (2008) defines economic globalization as the rapid rise in the sharing of economic activities in the world between people of different countries. This suggests that these cross-border economic activities can be placed into three broad groups: (i) the cross-border exchange of goods and services via international trade, (ii) the establishment and operation of a firm in the foreign country by residents of the host country via foreign direct investment, and (iii) labor services offered by residents of the host country to residents of the foreign country via labor migration. Evidence that goods, capital and labor services have become increasingly globalized is seen in the following facts: the value of trade (goods and services) as a percentage of world GDP has increased from 42.1 percent in 1980 to 62.1 percent in 2007; foreign direct investment has increased from 6.5 percent of world GDP in 1980 to 31.8 percent in 2006; and the number of foreign workers has increased from 78 million people (2.4 percent of the world population) in 1965 to 191 million people (3.0 percent of the world population) in 2005 (IMF, 2008).

This has led to a contentious debate on whether countries that are increasingly economically integrated with the rest of the world have seen an increase in economic growth. Consequently, there have been a vast number of empirical studies focusing on the impact that relatively more outward oriented economies have on economic growth and productivity. Studies of outward oriented activities include all three forms of cross-border activities; international trade (Frankel and Romer, 1999; Irwin and Terviö, 2002; Edwards, 1998 and Lee, Ricci and Rigobon, 2004); foreign direct investment (Borensztein et al, 1998; Alfaro et al, 2003; Balasubramanyam et al, 1996) and migration (Dolado et al, 1994; Lundborg and Sergestrom, 2002; Ortega and Peri, 2009; Morley, 2006).

When examining this issue, most empirical studies use a cross-country regression framework on a sample of developed and developing countries. Apart from the basic factors of production such as labor and capital, growth accounting regressions look for additional determinants that can explain growth. This leads to a regression treating all determinants of output growth as inputs which is conceptually incorrect since many included determinants may only indirectly affect output (Miller and Upadhaya, 2000). However, output growth is typically explained as the accumulation of factor inputs and the growth of total factor productivity. Hence we could have the additional determinants of output growth (beyond the factor inputs) affecting the efficiency of real inputs, physical capital and labor, and thus directly affecting factor productivity. Productivity growth, in general, comprises of two mutually exclusive parts, technological change and efficiency change, and stochastic frontier analysis (SFA) allows us to distinguish between the two. A SFA framework allows us to see whether the effect of cross-border activities on productivity growth occurs via technology change or efficiency. We can then quantify the impact of cross-border activities on efficiency levels and make inferences about the contributions of these cross-border activities in affecting efficiency.

This can be further understood by viewing output growth from the perspective of a production possibilities frontier where countries can be operating either on or within the frontier, with the distance from the frontier reflecting inefficiency. Over time, a country’s frontier can shift, indicating technological change, or a country can move towards or away from the frontier, which represents efficiency changes. Moreover, a country can move along the frontier by changing inputs. So productivity growth can be seen as being made up of three components: efficiency change, technology change and input change with the first two components being the "productivity change" (Koop et al 2000a).

The purpose of this study is to re-examine the growth effects of outward oriented economies by using a stochastic frontier model to measure the efficiency externalities of all three forms of cross-border economic activities associated with globalization. There have been a limited number of macroeconomic empirical studies which have used SFA to examine the impact of either trade, or foreign direct investment, or both on productivity. Kneller and Stevens (2006) use SFA to to study the efficiency effects of human capital and R&D undertaken by an industry on technological efficiency for a sample of OECD industries at the industry level from 1973-1981. They find that human capital affects a country's efficiency while R&D has an insignificant effect on efficiency. Iyer et al (2008) use SFA to study OECD countries from 1982-2000 and find that trade and FDI inflows increase efficiency whilst FDI outflows increase inefficiency. [1] The SFA framework is also used by Mastromarco and Ghosh (2009) who examine the efficiency effects of FDI and human capital for developing countries from 1981-2000 and find that FDI, imported capital goods, and imported R&D are important channels for improving efficiency, as is human capital accumulation. Finally, a recent paper by Wijeweera et al (2010) looks at FDI flows for 45 countries from 1997 to 2004 and finds that FDI inflows have a positive impact on economic growth in the presence of a highly skilled labour force. However,

[1] The present study which is the closest to Iyer et al. (2008) still differs with it in a number of important ways. First, the present study emphasizes the effects of migration on technical efficiency, though it takes into account the role of all other outward activities and absorptive capacity proxied by human capital. Second, while Iyer et al. (2008) stress the difference between inward and outward FDI and the relative size of R&D knowledge spillovers, the present study highlights the effect of migration on efficiency spillovers through the human capital channel in the host country. Third, this study has larger country coverage, 24 OECD countries, and a more recent the period coverage from 1993-2004.

they find that a country cannot improve its efficiency without a skilled labor force. By not including all the cross-border activities in explaining the efficiency externalities of openness the robustness of the results obtained in the earlier studies can be called into question. The positive effect of one or more openness channels on efficiency may depend on correlated omitted variables. This issue is particular important when the purpose is to assess the effect of openness on a country's productivity.

This study contributes to the earlier existing literature on the impact of increased economic globalization on growth by including economic activities across countries in the goods market, capital market and labor market and thus is a comprehensive approach to study outwardly oriented economies. Additionally, to the best of our knowledge, this is the first cross-country study to examine the efficiency impact of immigration on total factor productivity. If all channels of outward orientation are not included then there can be a bias in the estimation of the growth impact of the channels included, or an underestimation of the growth effects of outward orientation in general (Hejazi and Safarian, 1999). None of the previous studies that use a SFA framework consider openness in the labor market. Dumont et al (2010) reports that 68 percent of all migrants in the OECD database, DIOC-E, live in OECD countries.[2] Immigration, therefore, can potentially be an important source of productivity gains in OECD countries and excluding this measure could bias results since FDI and trade, the two measures typically used in the literature, can be correlated with migration. To understand this better, consider the example in Figure 1. It compares the output of two production units, country A and country B, as a function of labor, L. Given the same production technology, the higher output in country A compared to country B can occur for four possible reasons. First, this difference can be due to differences in

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[2] OECD's database DIOC-E (release 2.0) covers 89 destination countries for migrants, of which 61 are outside the OECD area. It includes information on 110 million migrants aged 15 and over. This represents around 72% of the estimated number of international migrants worldwide.

input levels, as is the case in panel I. Second, technology acquisition may differ between production units or countries, with the consequence that for the same level of inputs different outputs result, as in panel II. Third, it might be that country B produces less efficiently than country A. In other words, both production units have the same frontier and the same input level, but output in B is lower (see panel III). Fourth, differences could be due to some combination of the three causes. In our specification, foreign direct investments and trade can affect the country's output as efficiency factors, whereas immigration can affect the country's output through two different channels: first, as a production factor (included in the labor force) and, second, as the efficiency factor.

Moreover, this study contributes to the literature by including human capital into the stochastic frontier model which can reveal how human capital stock in host countries impacts the efficiency levels affected by each of the three cross-border activities. We thus acknowledge the endogenous growth models of Lucas (1988) and Romer (1990) that use a theoretical framework where persistent economic growth is conditional on the accumulation of human capital.[3] The level of human capital determines how well an economy absorbs the transfer of knowledge and technology that occurs through international trade, FDI flows, or migration. This has particular relevance for the immigration channel of outward orientation since immigrants can contribute to the host country's human capital base by bringing their own skills to the host country and by influencing the natives' knowledge accumulation. Thus, they can potentially impact total factor productivity via its impact on the host country's human capital. Also, by including human capital into the empirical framework we can ensure that efficiency changes due to human capital are not interpreted as changes arising from trade, FDI, or migration. Thus we estimate a stochastic

[3] Empirical studies by Benhabib and Spiegal (1994), Dinopoulos and Thompson (2000) and Bils and Kelnow (2000), which incorporate the suggestion of endogenous growth models that human capital is a factor influencing productivity growth, find its impact to be significant.

production frontier for 24 Organization for Economic Development and Co-operation (OECD) countries for the period 1993-2004 to determine how total factor productivity can increase through international trade, foreign direct investment, and immigration. We limit our work to studying OECD countries because the stochastic frontier model assumes a common production technology frontier for all countries in the sample, and pooling developed and nondeveloped countries together would be erroneous conceptually. We also apply a non-parametric technique exploiting more recent methods for Data Envelopment Analysis proposed by Simar and Wilson (2007) to check the robustness of our results using SFA.

We find two important results in our study. First, we find that international trade and FDI are important channels for improving efficiency, as is human capital accumulation. However, as expected, migration measured as the number of immigrants, increases inefficiency because this is equivalent to producing the same output by a large number of people. It is therefore important to consider whether immigrants bring enough human capital along with them. For this purpose, we insert a quality-adjusted measure of migrants by interacting the number of migrants with the human capital variables. In doing so we assume that the share of migrants with secondary (or tertiary) education is equal to that of the resident population. Second, we find that the effects of international trade, FDI, and migration on efficiency depend crucially on the level of accumulated human capital in a country. Our results show that in order to increase efficiency via FDI activities, OECD countries need a labor force with tertiary education levels, whereas to increase efficiency via international trade activities, OECD countries need a labor force with secondary education levels. More importantly, we find that immigration to countries that are richer in human capital enhances efficiency relatively more when compared to immigration into countries with lower human capital. We find that our results remain robust to different measures of human capital, controls on education levels among immigrants, and to nonparametric estimation of the model.

The remainder of the paper is organized as follows. In section 2, we discuss the linkages between the three cross-border activities, human capital and productivity. We then construct the empirical model in section 3 and discuss the data in section 4. In section 5, we discuss the empirical results. We conclude in section 6.

2. Linkages between Cross-Border Activities, Productivity and Human Capital

Increases in total factor productivity occur through at least three cross border economic activities – international trade, FDI and migration. Additionally, there is ample evidence in the literature, both theoretical and empirical, that human capital matters in increases in total factor productivity. [4] In this section we briefly review the literature on the nexus between each of the cross-border activities (international trade, FDI, immigration), human capital, and productivity.

International trade, human capital and productivity

The benefits accruing to countries that trade more are seen in the higher rates of technological progress which can result from both access to a larger international market that provides technological spillover effects and higher profits to innovators, and the economies of scale in research and development (Grossman and Helpman (1990, 1991; Krugman, 1990; Rivera-Batiz and Romer, 1991). Typically, the measure of international trade is the ratio of exports and imports relative to GDP. For example, Romer (1992) and Barro and Sala-i-Martin (1995) argue that a more open economy leads to more efficient techniques of production and better access to investment goods. This leads to faster productivity growth and, hence, higher

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[4] Growth economists have done extensive work on the role of human capital in the process of economic growth and research points towards the fact that various measures of mean years of schooling are correlated with growth rates in productivity (e.g. Barro, 2001; Barro and Sala-i-Martin, 1995; Benhabib and Spiegal, 1994; O'Neil, 1995).

real per capita income. Some of the early empirical studies that provide evidence for the argument that trade openness promotes productivity through technology are Coe and Helpman (1995), Coe et al (1997) and Keller (1998), where imports are considered to be a means of introducing foreign technology into domestic production and raising total factor productivity. They show that countries that have imported more machinery and equipment from world technology leaders have seen faster growth in total factor productivity. Empirical studies by Alcalá and Ciccone (2004), Frankel and Romer (1999), and Irwin and Terviö, (2002) examine the relationship between openness and productivity using cross-country data and find that higher trade share increases productivity.

How does human capital affect productivity through its interactions with international trade? Grossman and Helpman (1991) suggest that increased trade orientation can interact with human capital resulting in higher economic growth. Theoretically, trade can increase on-the-job human capital accumulation by transferring technology from the technologically more advanced economies to the less advanced economies. This can both increase the knowledge of workers and lead to an increase in the wages of skilled workers relative to unskilled workers which induces workers to invest more in human capital (Hall and Jones, 1999; Goh and Oliver, 2002). However, Stokey (1991) and Young (1991) show that, theoretically, openness can also decrease on-the-job human capital accumulation if trade causes countries to import high-quality goods rather than produce them. Dömeland (2007) empirically provides evidence that trade increases on-the-job human capital accumulation as measured by the U.S. returns to home country experience of U.S. immigrants from different source countries. Miller and Upadhyay (2000) find that the negative effect of human capital on the total factor productivity of low-income countries changes to a positive effect as a country moves from a lower to a higher level of openness.

Foreign direct investment, human capital and productivity

Foreign direct investment (FDI) leads to increases in productivity by spurring competition and transferring technology. New foreign competition arrivals provide domestic firms an incentive to use existing resources more efficiently which increases their productivity. Consequently, foreign firms have to invest even more in order to keep up with their technological advantage (Glass and Saggi, 1998). FDI can also increase productivity through the transfer of technology. This occurs with the adoption of new technology brought by foreign multinational companies, imports of high-technology inputs, and the skills acquired by the local labor force as they are educated and trained by the foreign firms. Using these arguments, Borensztein et al (1998), De Mello (1999) and Xu (2000) conclude that FDI increases an economy's productive efficiency. Javorcik (2004) argues that FDI can also raise productivity growth through vertical spillovers rather than horizontal spillovers.[5]

For multi-national corporations operating in skill-intensive industries, the general level of human capital is very important (Blomström and Kokko, 2003; Miyamoto, 2003). Typically, education is used as the measure of human capital. In examining the impact of human capital on productivity gains arising from FDI flows, Borensztein et al (1998) and Xu (2000) empirically show that the impact of FDI on per capita growth depends upon the accumulated threshold level of human capital in the host economy. Using the SFA framework, there have been several studies that have examined the FDI-human capital nexus. Mastromarco and Ghosh (2009) find that FDI improves efficiency, as does human capital accumulation. In addition, they find that in the process of technology diffusion, the impact of formal education is less important for FDI, whereas human capital measured as learning by doing, is found to be more important for

[5] Horizontal spillovers are associated with productivity spillovers from foreign firms to local firms in the same sector whereas vertical spillovers arise from interactions between foreign firms and their local suppliers (backward linkages) and foreign firms and their local customers (forward linkages).

knowledge diffusion through FDI which "supports the view of complementarities between disembodied knowledge of multinational firms and the absorptive capacity in host countries." (p. 499). Similarly, Wijeewera et al (2010) find that FDI inflows exert a positive impact on economic growth in the presence of a highly skilled labor but FDI by itself does not induce efficiency gains. A nation needs to have a well-trained and skilled labor force in place so that it can absorb the advanced technology that accompanies FDI inflows. However, Iyer et al (2008) find that the efficiency externalities that stem from foreign investment are not conditional on the proportion of higher educated people in the host country. The efficiency externalities from foreign investment are contingent on the absorptive capacity of the host economies as reflected in their financial markets.

Migration, human capital and productivity

Immigration, as a source of population growth, shares the same association as population growth in neoclassical theory in that it reduces per capita output and growth.[6] However, in a simple neoclassical growth model where (i) production is a function of labor and human capital, which are internationally mobile, and physical capital which is immobile; (ii) there is no trade between countries; and (iii) exogenous technological progress is the principal driving force of economic growth, the human capital endowments of migrants is the decisive factor favoring economic growth. The key then is to determine whether immigrants bring enough human capital along with them to compensate for the decrease in physical capital per capita in the host country. From this perspective, immigrants with low human capital endowments slow down per capita growth, while immigrants with high endowments of human capital will speed up per capita growth. This argument becomes even more significant for models of endogenous growth.

[6] A detailed discussion of this issue is provided by Barro and Sala-i-Martin (1995). Rothgang and Schmidt (2003) and the survey by Friedberg and Hunt (1995) also provide insight into this issue.

Overall, the results of empirical studies on the linkages between immigration and growth come to conflicting results (Friedberg and Hunt, 1995). Barro and Sala-i-Martin (1992), for example, find that for the United States and Japan, migration has a positive, though small, effect on growth. Peri (2009) in a regional study of openness amongst the 50 U.S states looks at the effect of immigrants' inflows on total factor productivity for each U.S. state and finds that the openness of a state positively affects productivity through immigration but not through trade. However, the empirical results of Blanchard and Katz (1992) and Dolado et al (1994) conclude that migration is negatively related to the convergence between regions while Ortega and Peri (2009) conclude that immigration has no effect on total factor productivity. However, when Dolado et al (1994) includes the human capital brought in by immigrants, the negative output and growth effects of immigration become less important. This is because immigrants can contribute to the host country's human capital base by bringing their own skills to the host country and by influencing natives' knowledge accumulation.[7]

4. Empirical Model

We consider a standard growth model with externalities (Romer, 1986; Lucas, 1988). The product of a country *i* at time *t*, Y_{it}, is determined by the levels of labor input and private capital, L_{it} and K_{it}. The level of technology or multi-factor productivity is given by the parameter *A*. The production function is expressed as follows:

$$Y_{it} = F(A_{it}, L_{it}, K_{it}) \tag{1}$$

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[7] The contribution of immigrants' human capital levels is also exploited by Hendricks (2002) which looks at cross-country income differences by estimating the human-capital endowments embodied in immigrant workers from different countries based on earnings attained in a common labor market. This approach allows them to conclude that human and physical capital does not account for the majority of cross-country income differences.

The parameter A_{it} describes the Hicks-neutral productivity and is assumed to be affected by a set of variables, Z_{it}, which are external to an individual country. Equation (1) can thus be rewritten as:

$$Y_{it} = A_{it}(Z_{it})F(L_{it}, K_{it}) \tag{2}$$

Equation (2) indicates that the level of total factor productivity, $TFP_{it} = A_{it}\ (Z_{it})$ depends on the (embodied and disembodied) technological progress, A_{it}, and on external covariates such as a set of growth determinants, Z_{it}. Among these growth determinants we can consider, for instance, the contribution of human capital and the outward orientation measures such as international trade, migration, and FDI.

Following the efficient frontier literature (e.g., Färe et al., 1994), the TFP_{it} component can be further decomposed into the level of technology, A_{it}, an efficiency measure, τ_{it}, which depends on the covariates Z_{it}, and a measurement error, $w_{it,}$ which captures the stochastic nature of the frontier,

$$TFP_{it} = A_{it}\tau_{it}(Z_{it})w_{it} \tag{3}$$

where $0 < \tau_{it} < 1$.[8] By writing equation (2) in translog form we thus have:

$$y_{it} = \beta_0 + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 \frac{1}{2}k_{it}^2 + \beta_4 \frac{1}{2}l_{it}^2 + \beta_5 k_{it} l_{it} + \beta_6 t + \beta_7 t^2 + \frac{1}{2}\beta_8 t k_{it} + \frac{1}{2}\beta_9 t l_{it} - u_{it} + v_{it} \tag{4}$$

where lower case letters indicate the previously defined variables in natural logs [i.e., $y_{it} = \ln Y_{it}$)], $u_{it} = -\ln(\tau_{it})$ is a non-negative random variable which measure inefficiency (distance from the efficiency frontier); and $v_{it} = \ln(w_{it})$ is the error term. Non neutral technology is captured by a time trend, t, in translog form in order to take into account the possibility of non-neutral technological shocks. Expected inefficiency is specified as:

[8] When $\tau_{it} = 1$ there is full efficiency, in this case the country i produces on the efficient frontier.

$$E(u_{it}) = \mathbf{z_{it}}\delta, \tag{5}$$

where u_{it} is assumed to be independently but not identically distributed, $\mathbf{z_{it}}$ is the (1x K) vector of covariates which influence TFP via inefficiency, and δ is the (K x 1) vector of coefficients to be estimated.

We thus model the inefficiency of OECD countries as:

$$\begin{aligned} u_{it} &= \delta_0 + \delta_1 FDI_{it} + \delta_2 trade_{it} + \delta_3 SEC_{it} + \delta_4 TER_{it} + \delta_5 Migr_{it} + \delta_6 SEC * Migr_{it} + \delta_7 TER * Migr_{it} + \\ &+ \delta_8 SEC * FDI_{it} + \delta_9 TER * FDI_{it} + \delta_{10} SEC * trade_{it} + \delta_{11} TER * trade + + \varepsilon_{it} \end{aligned} \tag{6}$$

where, *FDI* represents the foreign direct investments of country *i* at time *t*; *trade* measures trade openness and is equal to the ratio of the sum of imports and exports of manufactured goods to GDP; *SEC* and *TER* are two measures of human capital equal to the percentage of total labor force with secondary education and the percentage of the labor force with tertiary education in the population of country *i* at the end of year *t*; *Migr* is migration as inflows of foreign population; *SEC*Migr*, *TER*Migr*, *SEC*FDI*, *TER*FDI*, *SEC*trade*, and *TER*trade*, are the interaction terms of the openness indicators and human capital in the country. The hypothesis here is that the effect of all the cross-border activities on efficiency depends on the level of human capital. Finally, ε_{it} is white noise. In order to estimate the parameters of the production function in equation (4) together with the parameters in equation (6), we use a single-stage Maximum Likelihood procedure proposed by Kumbhakar (1991) and Reifschneider and Stevenson (1991). This is in the modified form as suggested by Battese and Coelli (1995) for panel data with time-variant technical efficiency. [9]

[9] MLE is used to take into consideration the asymmetric distribution of the inefficiency term (Aigner et al. 1977). Greene (1990) argues that the only distribution which provides a maximum likelihood estimator with all desirable properties is the Gamma distribution. However, following van den Broeck et al. (1994), the truncated distribution function, which better distinguishes between statistical noise and inefficiency terms, is preferred.

4. Data

The data set is a panel of twenty four Organization for Economic Development and Cooperation (OECD) member countries (Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States). Due to lack of data availability, the observation period is restricted to 1993-2004.[10] The dependent variable is the log of real GDP and the independent variables are the log of the labor force and physical capital. The GDP data are from the World Bank (World Development Indicators, 2007). The labor series is from the OECD database on labor force statistics in OECD.Stat Extract (2009). We follow the methodology of Dhareshwar and Nehru (1994) for our data on physical capital stock and gross fixed investment data which are sourced from the OECD STAN database for Industrial Analysis.[11]

The explanatory variables for the efficiency term are the three cross border activities – trade, FDI flows and migration – and human capital. International trade is captured by the variable, *trade*, which is the sum of manufactured exports and imports as a percentage of GDP; the trade data are from the OECD statistics database, OECD.Stat Extract (2009). Foreign direct investment is measured as stock of FDI (as a percentage of GDP); the FDI stock data are from United Nations Conference on Trade and Development's (UNCTAD) World Investment Report

[10] The data on migration is the limiting factor which constraints the sample period from 1993 to 2004.
[11] The net capital stock is estimated as summation of past gross investment flows. For a particular country, capital stock is calculated as $K_t = K_t{-}1\ (1 - \theta) + I_t$; where K is capital stock, I is investment and θ is the rate of depreciation, that is assumed to be 6%, along the lines of Hall and Jones (1999), Bernanke and Gurkaynak (2001) and Iyer et al. (2008). It is assumed that all assets are retired from the capital stock at the moment when they reach the average service life - the same for all types of assets. As a result, each year new real investment is added, and it is assumed that repair and maintenance will keep the physical production capabilities of an asset constant during its average lifetime. Initial capital stocks are constructed by the assumption that capital and output grow at the same rate. Specifically, for countries with investment data beginning in 1970 we set the initial capital stock $K_{1970} = I_{1970}/(g + \theta)$, where g is the 10-year growth rate of output. The estimated capital stock includes both residential and nonresidential capital.

Annex Tables (2009). Migration is measured as the inflow of foreign population in each period and country and was obtained from the OECD Statistics database, OECD.Stat Extract (2009).[12] We use two measures for human capital from the World Bank (World Development Indicators, 2007). The first measure is the percentage of total labor force with secondary education and the second measure is the percentage of the labor force with tertiary education. The summary statistics for all the explanatory variables are provided in table 1.

5. Empirical Results

Production Function Results

There are some studies that estimate the stochastic frontier and calculate the efficiency term, and, as a second step, regress predicted efficiency on specific variables in order to study the factors which determine efficiency. However, such a two-stage procedure is logically flawed since it requires a first-stage assumption that the inefficiencies are independent and identically distributed. Kumbhakar (1991) and Reifschneider and Stevenson (1991) address this issue by proposing a single-stage Maximum Likelihood procedure. We adopt this approach but in the modified form as suggested by Battese and Coelli (1995).[13] They develop an extended version of Kumbhakar's model that allows the use of panel data. The parameters of the model defined by (4) and (6) are thus estimated simultaneously. The results of this estimation are displayed in table 2, where we report the coefficients of the translog form. From the estimates of technological parameters we can retrieve information on the most appropriate specification of the

[12] Our empirical resuls in section 5 do not change when we take immigration as a percentage of the labor force. These results are available upon request from the authors.
[13] We use MatLab for maximum-likelihood estimates of the parameters and predictions of technical efficiencies.

production function. By using a Likelihood-Ratio (LR) test we reject the null that the production function is the Cobb-Douglas in favor of the translog form.[14]

The coefficients of the translog production function cannot be directly given an economic interpretation. Therefore, in table 3 we report the estimated values of the output elasticities calculated at the average value for each input. The results displayed are based on variable means for the whole panel for the observation period, 1993-2004. As expected, all elasticities are positive and significant; output is elastic especially with respect to labor (about 0.60), while the output elasticity with respect to capital is lower (around 0.50).[15]

In order to further study the technology characterizing the production functions of firms, we check for the presence of linear homogeneity by testing the null hypothesis that the sum of the estimated elasticities is not statistically different from one. If we reject the null hypothesis, then we can infer that the technology presents increasing (decreasing) returns to scale when the sum of elasticities is above (below) unity. Table 3 (last row) shows that the hypothesis of constant returns to scale can be rejected and that the OECD countries exhibit increasing returns to scale.

Efficiency Results

In order to investigate the statistical relevance of inefficiency and analyze the determinants of inefficiency (i.e. the factors that have an impact on countries' total factor productivity) we first need to test the statistical (and economic) relevance of countries' inefficiency. The stochastic approach allows us to explicitly test for the presence of technical

[14] The Likelihood Ratio is used to test the null hypothesis is of a Cobb-Douglas functional form, i.e., $H_0 : \{\beta_3 = \beta_4 = \beta_5 = 0\}$. The Cobb-Douglas function is rejected. The test statistic is equal to 57.568, while the critical value of χ_3^2 at the 1 percent level of significance is equal to 10.501.

[15] The high labor elasticity is not surprising and confirms evidence found in other studies on different countries.

inefficiency in a specific production process. We test the null of the joint significance of the coefficients in equation (6), that is, $H_0 = \gamma = \delta_0 = ... = \delta_{11} = 0$. The test is based on the following variance parameters which are derived from equations (4) and (6)

$$\gamma = \frac{\sigma_u^2}{\bar{\sigma}^2}, \qquad \bar{\sigma}^2 = \sigma_u^2 + \sigma_v^2 \tag{8}$$

This parameter can be used to perform a diagnostic likelihood-ratio (LR) test.[16] The LR test statistic is approximately distributed following a mixed chi-square distribution. We find that the null hypothesis is decisively rejected at the 1 per cent level of significance.[17] Therefore, these results allow us to reject the null hypothesis of no inefficiency at the 1 percent significance level.

Since we find that inefficiency is significantly present in our sample of countries there is room to investigate its determinants, i.e., the factors that exert an impact on OECD countries' efficiency and, hence, on its total factor productivity. The analysis is based on equation (6), whose estimates are reported in table 2. Since inefficiency in equation (6) is measured in terms of the distance from the frontier, a negative impact indicates an increase in efficiency (i.e. catching up toward the frontier). Foreign direct investment *(FDI_{it})* has a negative sign and is statistically significant, indicating that its impact on efficiency is positive in table 2. Therefore, we find that countries with high levels of multinational activities perform well because of the benefits they get in terms of technical efficiency. While this finding supports earlier findings that FDI is a crucial dimension of countries performances (e.g. Borensztein et al., 1998; Findlay, 1978; Lichtenberg and van Pottelsberghe, 1998), it further shows that the channel through which

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[16] Coelli et al. (1998) point out that if $\gamma = 0$, the deviations from the frontier are entirely due to noise.
[17] Estimated statistic LR= 117.43, with a critical value of 25.549 for 12 degrees of freedom (for the critical values see Kodde and Palm 1986).

multinationals have an impact on production is by enhancing efficiency.[18] The coefficient on *trade*$_{it}$ has a negative sign, revealing that countries that have higher international trade are significantly more efficient. This is similar to results found earlier (e.g. Robbins, 1996; Tybout, 1992; Coe and Helpman, 1995; Coe et al., 1997).

With regards to the results of human capital variables, SEC_{it} and TER_{it}, we see that the coefficients are statistically significant with a positive sign for secondary education and a negative sign for tertiary education. This suggests that the efficiency externalities of human capital do depend on the proportion of a relatively higher educated labor force (our measure of human capital) of the country. We find that the channel through which human capital positively affects output is through the efficiency enhancing effect and thus confirm earlier studies (e.g. Benhabib and Spiegel 1994, Tallman and Wang, 1994). Recent contributions emphasize the different roles that different types of human capital may play in either backward or advanced economies (Caselli and Coleman 2006), and the distinction between innovation activities and adoption of existing technologies from the (world) technology frontier (Acemoglu et al., 2006). In this context, low skilled human capital appears better suited to adoption of technology in low income countries, while skilled human capital has a growth enhancing impact which increases with the level of development (Caselli and Coleman, 2006; Vandenbussche et al., 2006).

One of the aims of this study is to highlight the impact that migration can have on total factor productivity growth in OECD countries. The migration of people from less to more developed countries has long been a critical and unsolved issue. In deriving equation (6), we assume that, beyond just increasing the labor force, a further channel through which migration affects output is via efficiency. The empirical results support this choice. The coefficient of

[18] The fact that FDI flows enhance efficiency has also been seen in studies by Iyer et al (2008), Mastromarco (2008) and Mastromarco and Ghosh (2009).

$Migr_{it}$ is statistically significant (at the 10% significance level) and has a positive sign indicating that the higher the number of immigrants, the lower is the countries' efficiency. In other words, it appears that a higher number of immigrants slows down the technological catching up process.

Moreover, we argue that countries with higher levels of human capital benefit more from all three cross-border activities and, accordingly, we include the interaction terms of each of the cross border activities, migration ($Migr_{it}$), international trade ($trade_{it}$) and foreign direct investment (FDI_{it}) with human capital (SEC_{it} and TER_{it}) in equation (6). This set up allows us to examine the reaction of inefficiency (6) to each of the cross-border activity measures that are dependent on the level of human capital:

$$\frac{\partial E(u)}{\partial Migr} = \delta_5 + \delta_6 SEC + \delta_7 TER$$
$$\frac{\partial E(u)}{\partial FDI} = \delta_1 + \delta_8 SEC + \delta_9 TER$$
$$\frac{\partial E(u)}{\partial trade} = \delta_2 + \delta_{10} SEC + \delta_{11} TER. \tag{9}$$

We find that the coefficients on $SEC*Migr_{it}$ and $TER*Migr_{it}$ have a negative sign. However, only $TER*Migr_{it}$ is statistically significant which suggests that immigration into countries with a higher educated labor force enhances efficiency. As figure 2 (first graph) shows, the partial derivative of inefficiency with respect to immigration ($Migr_{it}$) depends on the level of human capital in the country (see equation 9). We see that the impact of immigration to inefficiency is first positive and then becomes negative at higher levels of human capital, which implies human capital-rich countries see their efficiency increase due to immigration unlike countries that are relatively low in human capital. In particular, Figure 1 shows that increasing migration will cause a positive effect on efficiency only at the last quantile of human capital distribution.

The coefficients on the interaction terms between human capital and the measures of international trade and foreign direct investment, $SEC*FDI_{it}$, $TER*FDI_{it}$, $SEC*trade_{it}$ and $TER*trade_{it}$, in table 2, are all statistically significant. However, only variables $TER*FDI_{it}$ and $SEC*trade_{it}$ have a negative sign indicating that its impact on efficiency is positive. By distinguishing between secondary and tertiary education levels, we can clearly disentangle the human capital channels through which FDI and international trade affect efficiency. Specifically, to better master the frontier technology, OECD countries need higher educated people (i.e. with tertiary education) for FDI and more basic knowledge (i.e. with secondary education) for international trade. Variables $SEC*FDI_{it}$ and $TER*trade_{it}$ have a positive sign indicating that the level of human capital seems to decrease the positive effect of FDI and trade on efficiency (see the second and third graph of Figure 2). This outcome might be determined by the measure of human capital used in the estimations, which is based on the average percentage of population with higher education, and thus is a mere proxy of general human capital (Becker, 1975).

Robustness Checks

We check to see if our results are: (i) robust to different measures of human capital; (ii) robust to new immigrants who enter the host country with tertiary education; and (iii) robust to a nonparametric estimation of the model. One of the main results of this study is that immigration has a negative effect on efficiency but helps to increase efficiency and productivity in the presence of higher levels of human capital. The other two cross border activities, FDI and trade, enhance productivity, FDI through tertiary education and trade through secondary education. In order to reach this conclusion we measured human capital as the percentage of labor force with secondary and tertiary education. This captures education as improvements in the skill level and knowledge of workers and is a source of human capital accumulation in the labor force over time. In order to check the robustness of our results to the above human capital measure, we use two alternate measures of human capital that have previously been used in the literature. Figures 3 and 4 present our robustness checks for the human capital measures. The first measure is the widely employed secondary and tertiary school enrolment rates. Figure 3 confirms our basic results and shows that education promotes efficiency externalities of immigration while it has little effect in boosting efficiency externalities of FDI and trade. The second measure is secondary and tertiary education expenditure per student. In Figure 4 we see that immigration has an increasingly positive impact on efficiency in the presence of more public investment in education (Chou and Wong, 2001). This supports the view of complementarities between human capital investment and immigration. In addition, we find that education expenditure acts as a substitute to foreign direct investments and as a complement to trade. This result seems to suggest that more public investment in education also helps people to better conduct trade in goods and services.

Our second robustness check stems from the observation that our results could be driven by the fact that we may not be controlling for levels of education among immigrants. Using data from the OECD Database on Immigrants in OECD Countries, we re-estimate our results for equations (4) and (6) using immigration data which includes only migrants with tertiary education. Our measures of human capital are the same as used in our baseline estimations, i.e., *SEC* and *TER* which are the percentage of total labor force with secondary education and the percentage of the labor force with tertiary education. Our estimation results, as shown in Table 4, reveals that this migration variable by itself has no effect on inefficiency. It is only when we interact this migration variable with existing human capital in host countries that we find the influence of migration on efficiency is positive. This lends further credence to the fact that our results are not driven by the fact that efficiency is improved due to the inherent human capital immigrants bring with them. The graphs in Figure 5 corresponding to Table 4 continue to reveal the same pattern as before with regard to the impact of immigration to inefficiency. It is first positive and then becomes negative at higher levels of human capital which implies human capital-rich countries see their efficiency increase due to immigration unlike countries that are relatively low in human capital. This result is confirmed for trade. However, for FDI it seems that, once we control for tertiary education levels amongst immigrants, knowledge transfer associated with FDI does not require further human capital to diffuse efficiency externalities.

A third robustness check stems from our awareness of the problems linked to the adoption of a parametric approach. Thus, in order to validate our results, we implement the non-parametric Data Envelopment Analysis (DEA) to estimate productive efficiency. An advantage of Data Envelopment Analysis (DEA), popularized by Charnes et al (1978), over SFA is that it does not make any assumptions, either about specific parametric functional form for the production frontier nor regarding distributional assumptions on the noise and inefficiency component. However, one problem with the DEA approach is that it is extremely sensitive to outliers (Aigner and Chu, 1968; Timmer, 1971) which can cause a bias in the estimated production frontiers and efficiency measures. Moreover, the standard DEA efficiency measures are point estimates and, therefore, it is not possible to construct standard errors and confidence intervals. The parametric or econometric approach, on the other hand, imposes a specification on the production function which of course can be overly restrictive. The parametric approach, SFA, does, however, have the advantage of having a well-developed statistical theory which allows for statistical inference. Hence, using SFA we can test the specification as well as different hypotheses on the efficiency term and on all the other estimated parameters of the production frontier such as input elasticities, scale economies, efficiency, etc.

Simar and Wilson (1998, 2000) propose a general methodology for bootstrapping in frontier models to analyze the sensitivity of efficiency scores relative to the sampling variations of the estimated frontier (i.e., to estimate the bias and variance, and to construct confidence intervals). We check to see how robust our results are following their method which is based on statistically well-defined models and allows for consistent estimation of the production frontier, corresponding efficiency scores as well as standard errors and confidence intervals. We thus estimate the effects of possible explanatory variables on efficiency using the double-bootstrap procedure for a truncated regression model proposed by Simar and Wilson (2007) to improve the robustness of statistical inference in the second stage. Using this method we assume that the observations are independent and identically distributed, ignoring the time dependence due to time dimension. Another important assumption we make in adopting the two stage approach proposed by Simar and Wilson (2007) is the separability condition of the efficiency factors and the production set; the covariates are assumed to affect the output only through the inefficiency (see p. 35 in Simar and Wilson, 2007).[19]

Table 5 presents our robustness checks when we use this methodology. The non-parametric estimations confirm our basic results which were obtained with parametric stochastic frontier estimation, i.e. that the positive effect of cross- border activities on efficiency depends crucially on the level of accumulated human capital. Specifically, immigration into countries enhances efficiency only when countries have enough domestic human capital.

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[19] If this condition is not supported by the data, the authors suggest that the parametric one stage approach of Battese and Coelli (1998) that is used in this paper should be applied.

6. Concluding Remarks

In a globalized world, outward oriented economies are integrated to the rest of the world in at least three different ways, through international trade, foreign direct investment flows and immigration. While proponents of globalization argue that these cross-border activities can have an impact on countries' technology convergence and thus their total factor productivity, there has not been a comprehensive study of outwardly oriented economies that includes all these cross-border economic activities. In this study we use a stochastic frontier model to study how total factor productivity can increase through international trade, FDI and immigration, for 24 OECD countries from 1993-2004.

The stochastic frontier approach allows us to distinguish between technological change and efficiency and thus allows us to analyse the efficiency externalities associated with flows in goods and services, flows in capital and flows in labor. The methodology thus allows us to estimate the contribution of international trade, FDI and immigration towards improving the efficiency with which the existing factor inputs and technology are utilized. To the best of our knowledge, this study is the first in the literature to investigate how cross-border economic activities affect the technology-catch up toward the frontier by considering flows in the goods market, the capital market and the labor market simultaneously. Previous work using SFA has used some of these cross-border activities to estimate its impact on total factor productivity (e.g. Kneller and Stevens, 2006; Iyer et al, 2008; Ghosh and Mastromarco, 2009; Wijeweera et al, 2010) but omitted variables could potentially bias the inefficiency term. If all the cross-border activities are not included in explaining the efficiency externalities of openness, it can compromise the robustness of the results of these papers. This issue is especially important if research focuses on the effect of outward oriented activities on productivity. In particular, Iyer et al (2008) find that trade and FDI inflows enhance efficiency, whereas FDI outflows increases the inefficiency of OECD countries. However, the positive effect of inflows of FDI and international trade on efficiency may depend on correlated omitted variables. By including cross-border activities stemming from the goods, capital and labor market, we ensure that we do not have a bias in the estimation of the growth impact or underestimate the growth effects of outward orientation in general. Moreover, by incorporating human capital into the model we acknowledge the fact that a host country's absorptive capacity from the externalities associated with the cross border activities can depend on the level of human capital stock.

Our results show that international trade and FDI are important channels that increase productivity by improving efficiency, as does human capital accumulation, while migration decreases inefficiency in countries that are richer in human capital. The results remain robust to alternate measures of human capital, controls on education levels among immigrants, and to a nonparametric estimation of the model. Human capital plays a significant role with regards to migration since immigration into countries that are richer in human capital enhances efficiency. Thus, to the best of our knowledge, this study is the first to document an important empirical finding that migration flows, when supported by human capital improvements, increases productivity via improving efficiency. This is also in line with the study by Peri (2009) for the 50 U.S. state economies where they conjecture that the increase in states' total factor productivity is due to native workers and immigrant workers undertaking more efficient task allocation which results in an overall efficiency gain. The results of this study convey an important message to policy makers in the host countries. Governments need to facilitate cross border activities, which include immigration flows, by encouraging the establishment of the necessary infrastructure and providing incentives to support the development of domestic innovative capabilities. For OECD countries, it will be more efficient and productive to invest in human capital and attract immigrants than adopting protectionism policies which would hamper productivity growth.

Figure 1: Production Function

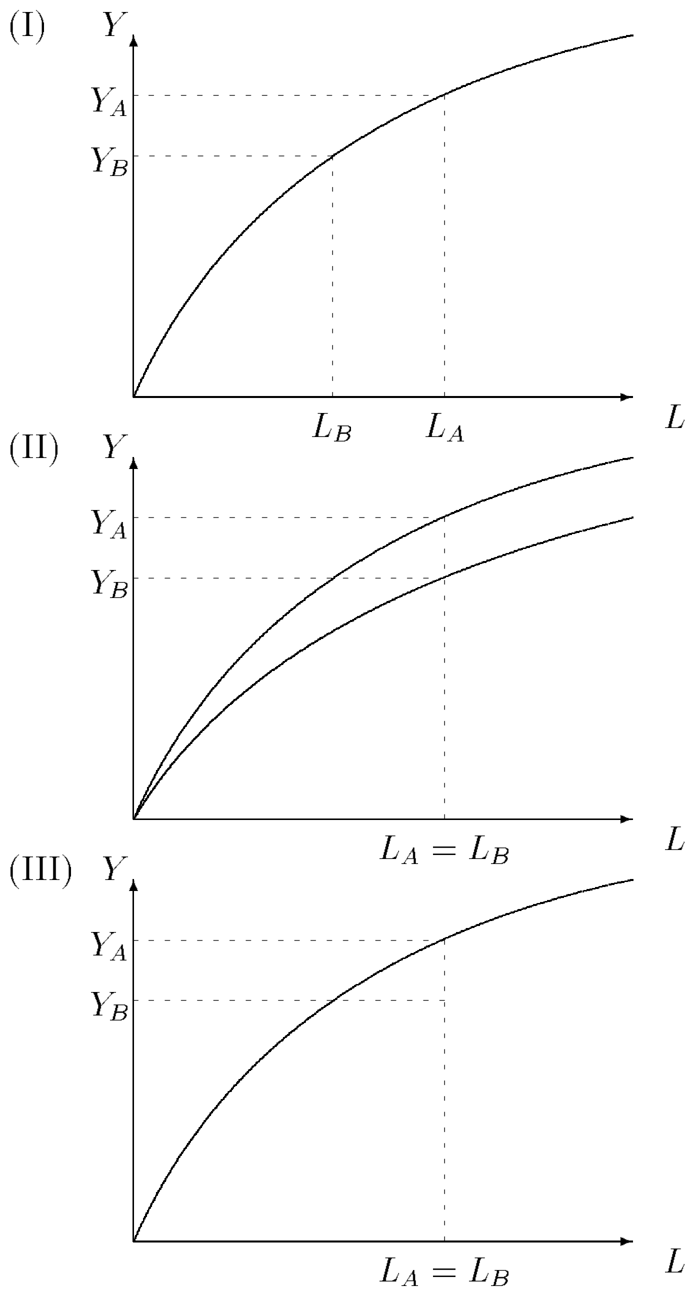

Table 1: Data Description (Mean)

Country		y	k	l	FDI	Trade	Sec. Educ	Tert. Educ	Migration
AUS	mean	26.67	27.09	16.56	1.90	39.97	32.194	36.726	108.39
	sd	0.14	0.13	0.07	2.55	2.26	9.7432	14.252	36.60
AUT	mean	25.94	26.48	15.60	1.83	83.68	65.905	11.615	64.91
	sd	0.09	0.12	0.09	1.22	11.80	2.2355	3.9006	31.73
BEL	mean	26.12	26.61	15.67	8.52	149.09	35.154	31.585	60.38
	sd	0.09	0.12	0.02	1.45	16.39	1.5522	3.3321	9.36
CAN	mean	27.23	27.26	17.05	2.71	76.36	30.477	50.631	217.83
	sd	0.13	0.10	0.07	2.35	7.10	0.49523	3.2438	25.32
DNK	mean	25.75	26.09	15.23	4.15	79.32	50.102	27.312	25.91
	sd	0.09	0.12	0.04	6.10	8.51	2.115	4.5727	9.56
FIN	mean	25.44	25.82	15.19	3.19	68.16	46.477	26.746	9.02
	sd	0.14	0.15	0.05	2.69	4.44	2.8833	6.029	1.83
FRA	mean	27.87	28.10	17.45	2.22	49.24	44.042	23.682	92.09
	sd	0.09	0.11	0.01	1.00	4.71	1.3845	2.6615	35.78
DEU	mean	28.23	28.63	17.80	1.67	59.17	54.477	21.954	691.11
	sd	0.06	0.13	0.03	2.79	10.50	8.3174	4.1973	112.73
IRL	mean	25.15	25.27	14.81	8.73	154.74	32.21	29.59	26.90
	sd	0.30	0.17	0.12	10.45	19.18	4.1446	7.5885	11.50
ITA	mean	27.69	28.08	17.48	0.74	47.92	38.123	10.966	263.96
	sd	0.06	0.11	0.03	0.42	4.09	4.1694	1.7476	73.32
JPN	mean	29.16	29.62	18.59	0.11	19.79	48.023	33.772	291.51
	sd	0.04	0.08	0.03	0.09	2.46	0.56591	3.4293	72.61
KOR	mean	26.91	27.68	17.79	0.83	69.33	43.408	23.969	216.96
	sd	0.19	0.23	0.03	0.62	10.56	0.58089	4.9515	37.90
LUX	mean	23.64	24.55	12.94	56.71	239.26	32.222	22.842	10.86
	sd	0.18	0.18	0.12	44.94	38.21	16.053	9.8572	1.25
NLD	mean	26.61	27.00	16.15	6.05	119.89	43.568	24.842	73.76
	sd	0.10	0.12	0.06	4.84	9.59	1.2039	1.8813	13.75
NZL	mean	24.67	25.02	15.01	3.72	60.49	36.266	40.885	47.23
	sd	0.12	0.17	0.08	1.79	4.25	18.099	14.506	15.79
NOR	mean	25.79	26.60	14.98	2.01	71.73	56.275	29.492	24.27
	sd	0.12	0.14	0.03	1.29	2.60	0.65106	2.7995	6.25
PRT	mean	25.37	26.56	15.97	2.43	64.58	11.76	10.635	28.96
	sd	0.11	0.10	0.04	1.87	3.23	1.4666	1.4153	41.56
ESP	mean	27.04	27.43	17.11	2.93	51.88	18.375	25.051	268.78
	sd	0.14	0.13	0.14	1.73	7.23	2.4359	4.3999	231.34
SWE	mean	26.16	26.40	15.70	5.97	77.56	51.338	27.262	41.75
	sd	0.11	0.09	0.03	5.91	8.31	3.8504	1.246	7.14
CHE	mean	26.19	27.56	15.73	2.57	76.20	59.546	23.185	89.90
	sd	0.06	0.06	0.01	2.21	7.79	1.4791	2.4447	12.87
GBR	mean	27.95	27.89	17.64	3.42	55.65	46.362	25.269	245.21
	sd	0.11	0.10	0.03	2.51	2.10	1.4186	2.9375	99.32
USA	mean	29.85	29.77	19.31	1.34	23.95	45.846	41.038	755.13
	sd	0.13	0.09	0.04	0.89	1.51	10.778	12.914	213.09

Table 2. Estimation Results

Parameter	Estimate	t-Ratio
Production Frontier		
Constant	-15.60500	-0.00003
k_{it}	8.83510	5.35655
l_{it}	-3.53030	-2.24345
$0.5k_{it}^2$	-0.66940	-4.20768
$0.5l_{it}^2$	-0.45700	-3.73519
$k_{it}l_{it}$	0.49150	3.50896
t	0.66015	4.16972
t^2	-0.01413	-1.72697
tk_{it}	-0.04535	-3.92760
tl_{it}	0.03037	3.11552
Inefficiency Model		
Constant	56.66900	0.00011
FDI_{it}	-0.01197	-3.68486
$trade_{it}$	-0.01339	-4.00323
SEC_{it}	0.01203	2.76722
TER_{it}	-0.02430	-5.54610
$Migr_{it}$	0.00098	1.55440
$SEC * Migr_{it}$	-0.00001	-1.19880
$TER * Migr_{it}$	-0.00002	-1.85157
$SEC * FDI_{it}$	0.00132	9.32743
$TER * FDI_{it}$	-0.00108	-6.87980
$SEC * trade_{it}$	-0.00014	-2.78182
$TER * trade$	0.00049	7.25872
σ_u	0.04198	0.00000
σ_v	0.32946	0.00024

Note: Number of observations: 286, log-likelihood: 94.178. The estimates in the first panel are the parameters of the translog production function and the coefficients of the time trend (in translog specification) (equation 4). The estimates in the second panel are the parameters of the inefficiency model (equation 6), σ_u the estimate of the standard deviation of the efficiency, and σ_v is the estimate of the standard deviation of the statistical noise.

Table 3. Elasticities

		Standard error
Capital Output Elasticity	0.50	(0.05) ***
Labour Output Elasticity	0.60	(0.04) ***
Returns to scale ($H_0 : \sum \beta_j = 1$)	1.09	(0.04) +++

Notes: *** implies significance at the 1 percent level;
+++: implies H_0 rejected at the 1 percent level.

Figure 2: Marginal Effect of Inefficiency with Respect to Cross Border Activities

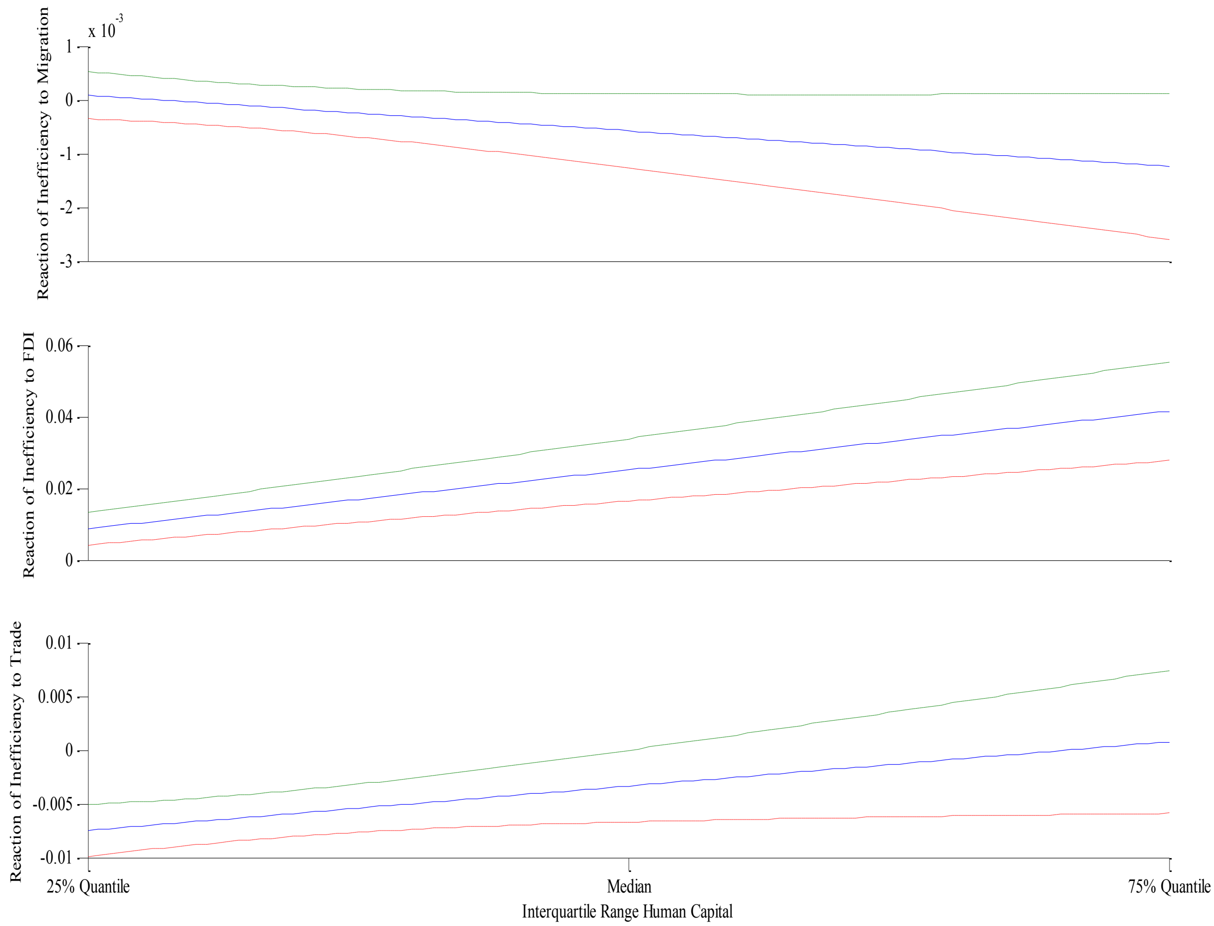

Figure 3: Robustness Check for Measure of Human Capital

Marginal Effect of Inefficiency with respect to Cross Border Activities using School Enrolment Rates

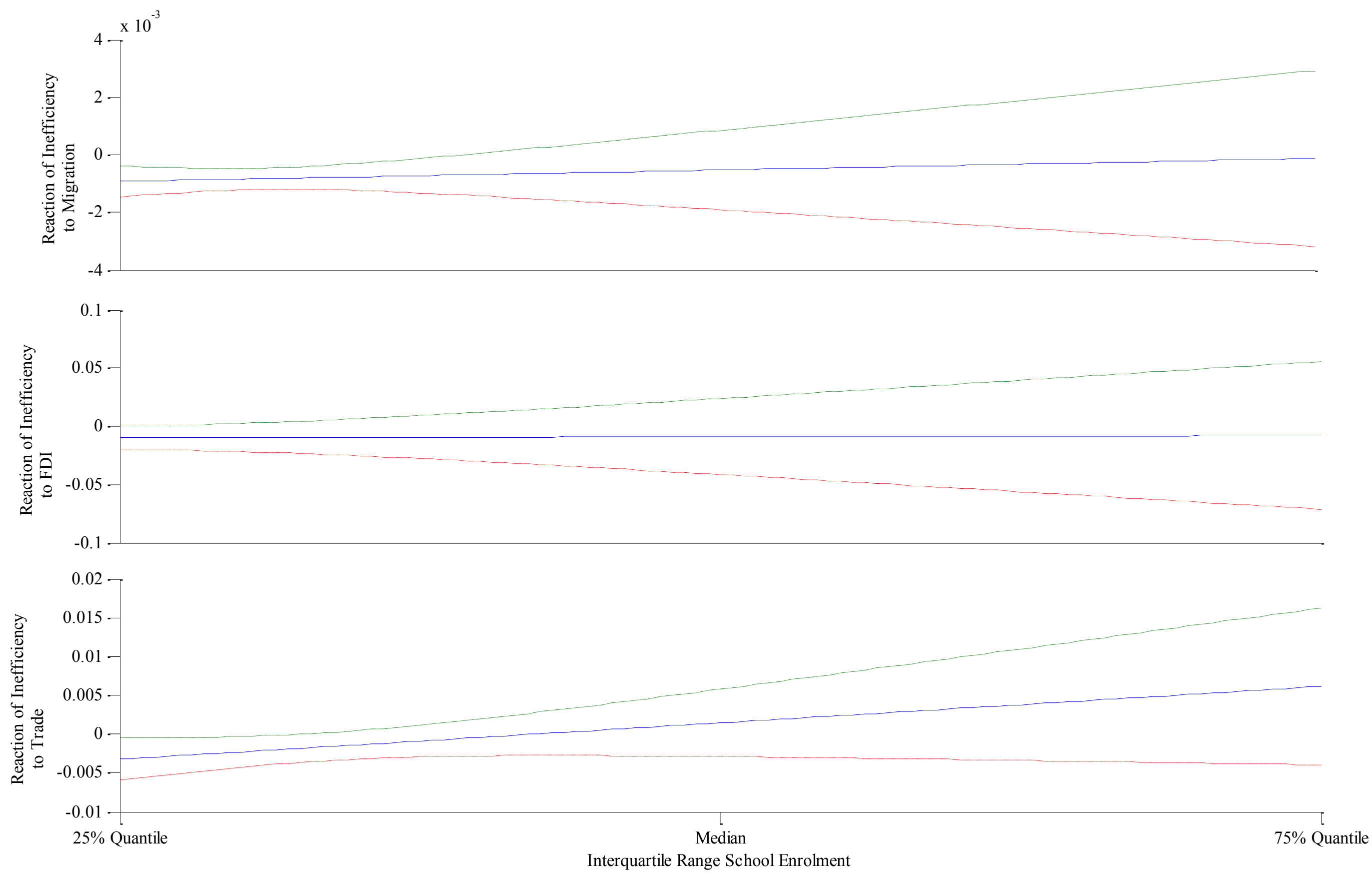

Figure 4: Robustness Check for Measure of Human Capital

Marginal Effect of Inefficiency with respect to Cross Border Activities using Education Expenditures per Student

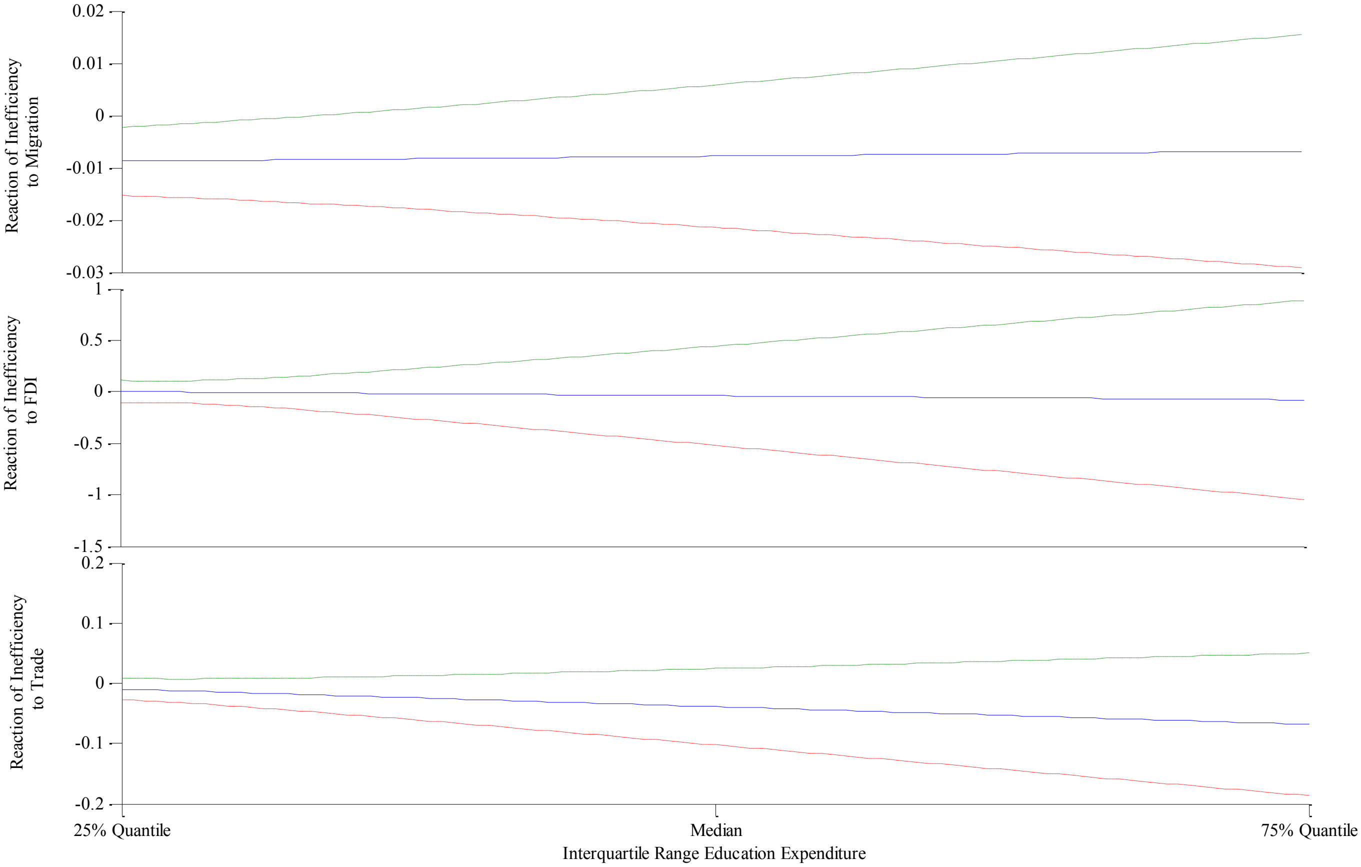

Table 4. Robustness Check Controlling for Immigrants with Tertiary Education Estimation Results

Parameter	Estimate	t-Ratio
Production Frontier		
Constant	-3.51420	-0.00010
k_{it}	9.85989	8.51030
l_{it}	-6.79494	-6.85277
$0.5k_{it}^2$	-0.63920	-7.25411
$0.5l_{it}^2$	-0.38087	-4.67928
$k_{it}l_{it}$	0.49743	6.15868
t	0.43373	4.46154
t^2	-0.01951	-3.77354
tk_{it}	-0.00970	-1.23427
tl_{it}	-0.00450	-0.59977
Inefficiency Model		
Constant	59.06136	0.00169
FDI_{it}	0.01247	5.56776
$trade_{it}$	0.00163	1.11584
SEC_{it}	0.02307	6.93055
TER_{it}	0.02290	7.23065
$Migr_{it}$	0.00002	12.66009
$SEC*Migr_{it}$	-0.00000	-12.79678
$TER*Migr_{it}$	-0.00000	-12.02927
$SEC*FDI_{it}$	0.00003	0.17395
$TER*FDI_{it}$	-0.00053	-3.76460
$SEC*trade_{it}$	-0.00003	-1.30600
$TER*trade$	0.00007	1.57121
σ_u	0.22803	0.00031
σ_v	0.06174	0.00002

Note: Number of observations: 286, log-likelihood: 13.829. The estimates $\beta_{0,\dots,5}$ are the parameters of the translog production function (equation 4), $\beta_{6,\dots,9}$ are the coefficients of the time trend (in translog specification). The estimates $\delta_{0,\dots,11}$ are the parameters of the inefficiency model (equation 6), σ_u the estimate of the standard deviation of the efficiency, and σ_v is the estimate of the standard deviation of the statistical noise.

Figure 5: Robustness Check Controlling for Immigrants with Tertiary Education

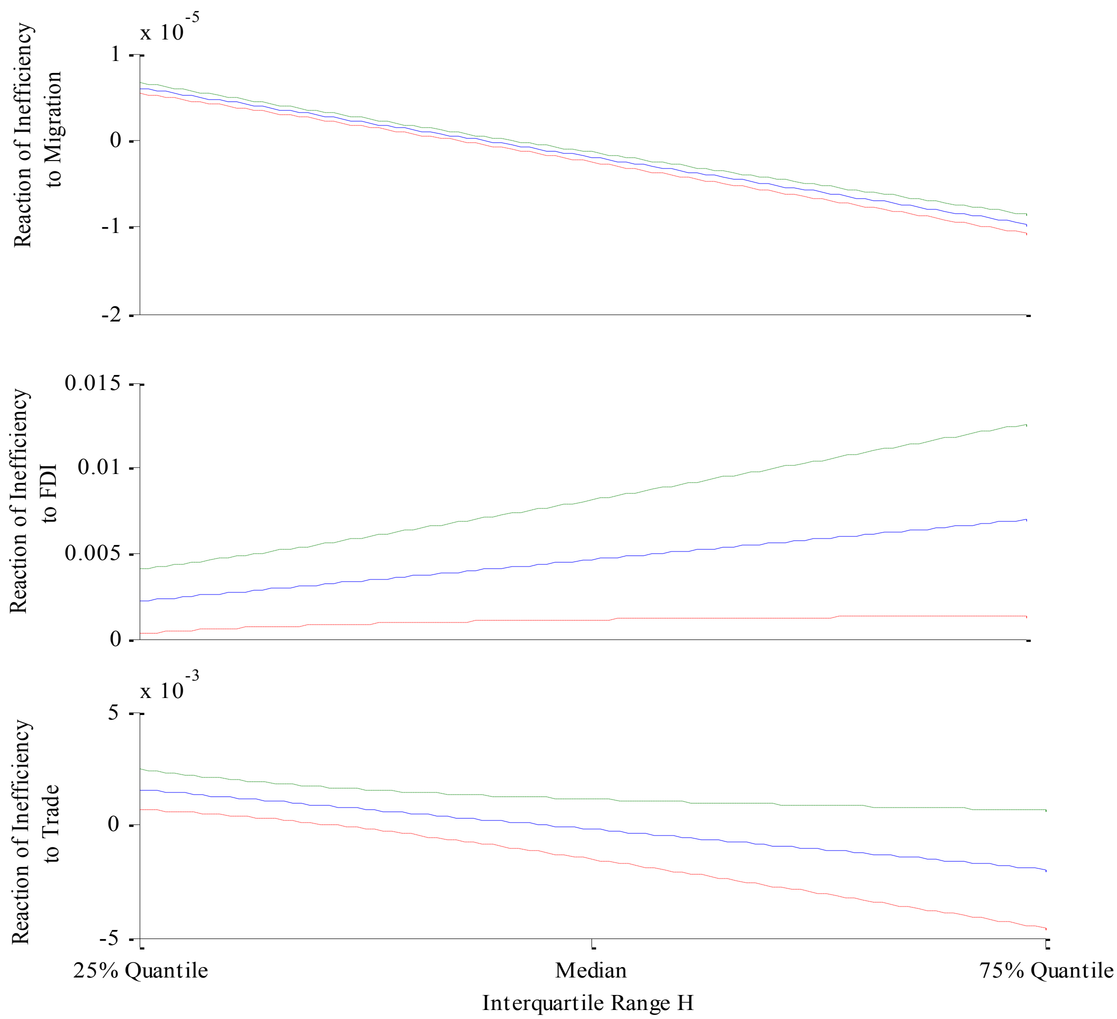

Table 5: Robustness Check for Empirical Methodology

Results of Truncated Regression Analysis

Parameter	Estimate
Constant	-18.05889*
FDI_{it}	0.00074*
$trade_{it}$	0.08246*
SEC_{it}	0.01995*
TER_{it}	0.15957*
$Migr_{it}$	0.00291*
$SEC * Migr_{it}$	0.00004
$TER * Migr_{it}$	-0.00022*
$SEC * FDI_{it}$	0.00296*
$TER * FDI_{it}$	-0.00055*
$SEC * trade_{it}$	-0.00110*
$TER * trade_{it}$	-0.00064*

Notes: * implies significance at the 5 percent level. The estimation is done according to Algorithm 1 and 2 of Simar and Wilson (2007) with 1,000 bootstrap replications for bias correction and 2,000 for confidence intervals of the estimated regression coefficient. The regressor is the DEA estimate of the unobserved inefficiency score of the countries. Estimations are done in MatLab.

Appendix

Variable	Description	Data Source
Y	Real GDP	World Development Indicators, 2007
K	Physical capital stock	Our calculations using gross fixed investment series from OECD STAN database for Industrial Analysis.
L	Labor force (number of workers)	OECD.Stat Extract, 2009
FDI	FDI inward stock, percentage of GDP	UNCTAD, World Investment Report Annex Tables, 2009
trade	Manufactured exports + manufactured imports / GDP	OECD Statistics database OECD.Stat Extracts, 2009
SEC	Percentage of total labor force with secondary education	World Development Indicators, 2007
TER	Percentage of the labor force with tertiary education	World Development Indicators, 2007
Migr	(i) Inflow of foreign population in each period and country	OECD Statistics database, OECD.Stat Extracts, 2009
	(ii) Inflow of foreign population in each period and country with tertiary education	OECD Statistics database, OECD.Stat Extract , 2009
Education Expenditure	Expenditure per student (percentage of GDP per capita)	World Development Indicators, 2007
School Enrolment Rates	Gross school enrollment rates which is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown	World Development Indicators, 2007

References

Acemoglu, D., P. Aghion and F. Zilibotti (2006), 'Distance to frontier, selection and economic growth', *Journal of European Economic Association* 4, 37–74.

Aigner, D. and Chu, S.:1968: On estimating the industry production function, *American Economic Review* 58, 826-839.

Aigner, D., Lovell, C. and Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models, *Journal of Econometrics* 6, 21–37.

Alcala, F. and Ciccone, A., 2004. Trade and productivity, *Quarterly Journal of Economics*, 119 (2), 613-646.

Alfaro, L., Chandra, A., Kalemli-Ozcan, S., and Sayek, S., 2003. FDI spillovers, financial markets, and economic development*, IMF Working Papers: 03/186*.

Balasubramanyam, V.N., Salisu, M., and Sapsford, D., 1996. Foreign direct investment and growth in EP and IS countries, *Economic Journal*, 106 (434), 92-105.

Barro, R.J., 2001. Human capital and growth, *American Economic Review* 91, 12-17.

Barro, R.J. and Sala-i-Martin, X., 1992. Regional growth and migration: A Japan-United States comparison, *Journal of the Japanese and International Economies*, 6 (4), 312-346.

Barro, R. J. & Sala-i-Martin, X. (1995). Economic growth. New York: McGraw Hill.

Battese, G. E. and Coelli, T. J.: 1995, A model for technical inefficiency effects in a stochastic frontier production function for panel data, *Empirical Economics* 20, 325–332.

Becker, G. S.: 1975, Human Capital, National Bureau of Economic Research and Columbia University Press, New York.

Benhabib, J. and Spiegel, M., 1994. The role of human capital in economic development: evidence from aggregate cross-country data, *Journal of Monetary Economics* 34, 143–173.

Bernanke, B. and Gurkaynak, R., 2001. Is growth exogenous? Taking Mankiw, Romer, and Weil seriously, *NBER Macroeconomics Annual* 16, 11–57.

Bils, M. and Klenow, P.J., 2000. Does schooling cause growth? *American Economic Review*, 90 (5), 1160-1183.

Blanchard, O. and L. Katz, 1992. Regional evolutions, *Brookings Papers on Economic Activity* 1, 1-61.

Blomström , M., and Kokko, K. (2003). Human capital and inward FDI, *CEPR Working Paper No. 167*, Centre for Economic and Policy Research, London.

Borensztein, E., De Gregorio, J. and Lee, L.-W.: 1998, How does foreign direct investment affect economic growth? *Journal of International Economics* 45, 115 -135.

Caselli, F. and Coleman, W. J.: 2006. The world technology frontier, *American Economic Review*, 96(3): 499–522.

Charnes, A., Cooper, W. and Rhodes, E.:1978. Measuring the efficiency of decision making units, *European Journal of Operational Research*, 2, 429-444.

Coe, D. T., Helpman, E. and Hoffmaister, A. W, 1997. North-south R&D spillovers, *Economic Journal* 107, 134-149.

Coe, D. T. and Helpman, E.: 1995, International R&D spillovers, *European Economic Review* 39, 859-87.

Coelli, T., Rao, D. and Battese, G.: 1998, An introduction to efficiency and productivity Analysis, Kluwer, Boston.

Chou, W., and Wong, K., 2001. Economic growth and international trade: The case of hong kong. *Pacific Economic Review*, 6(3), 313-329.

De Mello Jr., L.R., 1999. Foreign direct investment-led growth: evidence from time series and panel data, *Oxford Economic Papers*, 51 (1), 133-151.

Dhareshwar, A. and Nehru, V., 1994. New estimates of total factor productivity growth for developing and industrial countries. The World Bank Policy Research Working Paper Series, Paper No. 1313.

Dinopoulos, E. and Thompson, P., 2000. Endogenous growth in a cross-section of countries, *Journal of International Economics*, 51 (2), 335-362.

Dolado, J.J., Goria, A., and Ichino, A., 1994. Immigration, human capital and growth in the host country: evidence from pooled country data, *Journal of Population Economics*, 7 (2), 193-215.

Dömeland, Dorte, 2007. Trade and human capital accumulation, evidence from U.S. immigrants, World Bank Policy Research Paper No. 4144.

Dumont, Jean-Christophe, Spielvogel, Gilles, Widmaier, Sarah (2010), "International Migrants in Developed, Emerging and Developing Countries: An Extended Profile", OECD Social, Employment and Migration Working Papers No.114, www.oecd.org/els/workingpapers

Edwards, Sebastian, 1998. Openness, Trade liberalization, and growth in developing countries, *Developing and Newly Industrializing Countries*, Vol. 1, 39-74.

Färe, R., Grosskopf, S., and Lovell, C.A. Knox, 1994. Production frontiers. Cambridge University Press, Cambridge, New York, and Melbourne. pp. xv, 296.

Findlay, R.: 1978, Relative backwardness, direct foreign investment, and the transfer of technology: a simple dynamic model, *Quarterly Journal of Economics* 92, 1-16.

Frankel, J.A. and Romer, D., 1999. Does trade cause growth? *American Economic Review*, 89 (3), 379-399.

Friedberg, R. M. and J. Hunt, 1995. The impact of immigrants on host country wages, employment and growth, *Journal of Economic Perspectives* 9, 23-44.

Glass, A.J and Saggi, K., 1998. International technological transfer and technology gap, *Journal of Development Economics* 55, 369-98.

Greene, W.: 1990, A gamma-distributed stochastic frontier model, *Journal of Econometrics* 46, 141–164.

Grossman, G. M. & Helpman, E., 1990. Comparative advantage and long run growth, *American Economic Review* 80, 796-815.

Grossman, G.M., Helpman, E., 1991. Innovation and growth in the global economy. MIT Press, Cambridge, MA.

Goh, Ai-Ting and J. Olivier, 2002. Learning by doing, trade in capital goods and growth, *Journal of International Economics*, 56, 411-444.

Hall, R.E. and Jones, C. I.: 1999. Why do some countries produce so much more output per worker than others?, *Quarterly Journal of Economics* 114(1), 83–116.

Hejazi, W. and Safarian, A.E., 1999. Trade, foreign direct investment, and R&D Spillovers, *Journal of International Business Studies*, 30 (3), 491-511.

Hendricks, L., 2002. How important is human capital for development? evidence from immigrant earnings, *American Economic Review*, 92 (1), 198-219.

International Monetary Fund, 2008. Globalization: A brief overview. Available at http://www.imf.org/external/np/exr/ib/2008/053008.htm

Irwin, D.A. and Tervio, M., 2002. Does trade raise income? Evidence from the twentieth century, *Journal of International Economics*, 58 (1), 1-18.

Iyer, K.G., A.N. Rambaldi and Tang, K.K., 2008. Efficiency externalities of trade and alternative forms of foreign investment in OECD countries, *Journal of Applied Econometrics* 23, 749-66.

Javorcik, B.S., 2004. Does foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkages, *American Economic Review* 94 (3), 605–627.

Keller, W., 1998. Are international R&D spillovers trade-related? Analyzing Spillovers among Randomly Matched Trade Partners, *European Economic Review*, 42 (8), 1469-1481.

Kneller, R. and Stevens, P.A., 2006. Frontier technology and absorptive capacity: evidence from OECD manufacturing industries, *Oxford Bulletin of Economics and Statistics*, 68 (1), 1-21.

Kodde, D. and Palm, F.: 1986, Wald criteria for jointly testing equality and inequality restrictions, Econometrica 54, 1243–1248.

Koop, G., Osiewalski, J., and Steel, M.F.J., 2000. Modeling the sources of output growth in a panel of countries, *Journal of Business and Economic Statistics* 18, 284-299.

Krugman, P. R. (1990). *Rethinking international trade*. Cambridge, MA: MIT Press.

Kumbhakar, S.: 1991, Estimation of technical inefficiency in panel data models with firm and time specific effects, *Economic Letters* 36, 43 - 48.

Lee, H.Y., Ricci, L.A., and Rigobon, R., 2004. Once again, is openness good for growth? *Journal of Development Economics* 75, 451-472.

Lichtenberg, F. and van Pottelsberghe de la Potterie, B., 1998. International R&D spillovers: A comment, *European Economic Review* 42, 1483 -1491.

Lucas Jr., R.E., 1988. On the mechanics of economic development, *Journal of Monetary Economics* 22, 3-42.

Lundborg, P. and Segerstrom, P.S., 2002. The growth and welfare effects of international mass migration, *Journal of International Economics*, 56 (1), 177-204.

Mastromarco, C., and S. Ghosh, 2009. Foreign capital, human capital, and efficiency: A stochastic frontier analysis for developing countries, *World Development* 37, 489-502.

Mastromarco, C. 2008. Foreign capital and efficiency in developing countries, *Bulletin of Economic Research,* 60.

Miyamoto,K, 2003. Human capital formation and foreign direct investment in developing countries. Organization for Economic Co-operation and Development (OECD) Paper No. 211. Available at SSRN: http://ssrn.com/abstract=668505

Morley, B., 2006. Causality between growth and immigration: An ARDL bounds testing approach, *Economics Letters* 90, 72-76.

Miller, S. and Upadhyay, M., 2000. The effects of openness, trade orientation, and human capital on total factor productivity, *Journal of Development Economics*, 63, 399–423.

Saleh M. Nsouli, 2008. Ensuring a sustainable and inclusive globalization. A speech given at the Universal Postal Union Congress. Available at http://www.imf.org/external/np/speeches/2008/072508.htm

O'Neill, D., 1995. Education and Income Growth: Implications for Cross-Country Inequality, *Journal of Political Economy*, 103 (6), 1289-1301.

Organization of Economic Development and Cooperation, 2009. OECD STAN database. Available at http://www.oecd-ilibrary.org/content/datacollection/stan-data-en

Organization of Economic Development and Cooperation, 2009. OECD.Stat Extracts. Available at http://stats.oecd.org/index.aspx

Ortega, F. and Peri G., 2009. The causes and effects of international migrations: Evidence from OECD countries 1980-2005, NBER Working Paper Series, NBER Working Paper No. 14833.

Peri, G. (2009). The Effect of immigration on productivity: evidence from US states, NBER Working Paper Series, NBER Working Paper No. 15507.

Rivera-Batiz. L. A. & Romer P. M. ,1991. International trade with endogenous technological change, *European Economic Review* 35**,** 971 - 1004.

Reifschneider, D. and Stevenson, R. 1991. Systematic departures from the frontier: A framework for the analysis of firm inefficiency, *International Economic Review* 32, 715–723.

Robbins, D., 1996. Evidence on trade and wages in the developing world, OECD Development Centre, Technical Paper no.119.

Romer, P.M., 1986. Increasing returns and long-run growth, *Journal of Political Economy*, 94 (5), 1002-1037.

Romer, P.M., 1990. Endogenous technological change, *Journal of Political Economy*, 98 (5), S71-102.

Romer, P.M., 1992. Growth based on increasing returns due to specialization, *The New Classical Macroeconomics* 3, 569-575.

Rothgang, M. and Schmidt, C.M. 2003. “The new economy, the impact of immigration, and the brain drain”, in D. C. Jones (ed.), *New Economy Handbook*. Amsterdam, New York and Tokyo: Elsevier Science.

Simar, L. and Wilson, P. W., 1998. Sensitivity analysis of efficiency scores: how to bootstrap in nonparametric frontier models, *Management Science* 44, 49-61.

Simar, L. and Wilson, P. W., 2000. A general methodology for bootstrapping in non-parametric frontier models, *Journal of Applied Statistics*, 27, 779-802.

Simar, L. and Wilson, P. W., 2007. Estimation and inference in two-stage, semi-parametric models of production process, *Journal of Econometrics*, 136, 31-64.

Stokey, N., 1991. The volume and composition of trade between rich and poor countries, *Review of Economic Studies* 58, 63-80.

Tallman, E. and Wang, P., 1994. Human capital and endogenous growth: evidence from Taiwan, *Journal of Monetary Economics* 34, 101–124.

Timmer, C,1971. Using a probabilistic frontier production function to measure technical efficiency, *Journal of Political Economy*, 79, 776-794.

Tybout, J. R., 1992. Linking trade and productivity: New research directions, *World Bank Economic Review* 6, 1892–11.

United Nations Conference on Trade and Development, 2009. World Investment Report Annex Tables. Available at http://www.unctad.org/Templates/Page.asp?intItemID=1465

Vandenbussche, J., P. Aghion and C. Meghir (2006), ‘Growth, distance to frontier and composition of human capital’, *Journal of Economic Growth* 11, 97–127.

van den Broeck, J., Koop, G., Osiewalski, J. and Steel, M., 1994. Stochastic frontier models: A bayesian perspective, *Journal of Econometrics* 61, 243–303.

Wijeweera, A., Villano,R. and B. Dollery, Brian, 2010. Economic growth and FDI inflows: A stochastic frontier analysis, *Journal of Developing Areas* 43, 143–58

World Bank, 2005. High income OECD. Available at http://siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1199807908806/HI-OECD.pdf

World Bank, 2007. World Development Indicators 2007. World Bank, Washington, D.C. pp. xxi, 402.

World Bank, 2008. What is globalization? Available at http://www1.worldbank.org/economicpolicy/globalization/ag01.html

Xu, B., 2000. Multinational enterprises, technology diffusion, and host country productivity growth. *Journal of Development Economics* 62, 477–493.

Young, Aylwin, 1991. Learning by doing and dynamic effects of international trade, Q*uarterly Journal of Economics* 106, 369-406.