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Author.
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“Is there some action a government of India could take that would lead the Indian economy to grow like Indonesia’s or Egypt’s? If so, what, exactly? If not, what is it about the “nature of India” that makes it so? The consequences for human welfare involved in questions like these are simply staggering: Once one starts to think about them, it is hard to think about anything else.”

Robert E. Lucas, Jr., 1988

“The world is still a closed economy, but its regions and countries are becoming increasingly open. . .. The international economic climate has changed in the direction of financial integration, and this has important implications for economic policy.”

Robert Mundell, 1963

ABSTRACT

This dissertation addresses commercial openness as a technology transfer channel using a database for 58 countries over a period of 45 years. It is proposed to identify the impact of openness in Total Factor Productivity (TFP) and to verify if the interaction between openness and internal technological efforts impacts productivity. We use a fixed-effect panel model in Instrumental Variables (IV) and the Generalized Method of Moments (GMM). The results suggest that TFP growth is not affected by long-term openness, although it has temporary positive effects. For developing countries, openness negatively affects TFP, even when variation in the degree of openness interacts with internal technological efforts.

Key-words: Knowledge Spillovers, Trade Openness, Productivity Growth, Panel Estimates.

RESUMO

Esta dissertação aborda a abertura comercial como canal de transferência de tecnologia usando uma base de dados para 58 países e um período de 45 anos. Propõe-se identificar o impacto da abertura na Produtividade Total dos Fatores (PTF) e verificar se a interação entre a abertura e os esforços tecnológicos internos impactam a produtividade. Utiliza-se assim um modelo de painel com efeito fixo em Variáveis Instrumentais (IV) e o Método Generalizado de Momentos (GMM). Os resultados sugerem que o crescimento da PTF não é afetado pela abertura a longo prazo, embora tenha efeitos positivos temporários. Em relação aos países em desenvolvimento, a abertura afeta negativamente a PTF, mesmo quando a variação do grau de abertura interage com os esforços tecnológicos internos.

Palavras-chave: Transbordamentos de Conhecimento, Abertura Comercial, Crescimento da Produtividade, Estimativas de Painel.

RESUMEN

Esta disertación investiga la apertura comercial como canal de transferencia de tecnología usando una base de datos para 58 países y un período de 45 años. Se propone identificar el impacto de la apertura en la Productividad Total de los Factores (PTF) y verificar si la interacción entre la apertura y los esfuerzos tecnológicos internos impactan en la productividad. Se utiliza así un modelo de panel con efecto fijo en Variables Instrumentales (IV) y el Método Generalizado de Momentos (GMM). Los resultados sugieren que el crecimiento de la PTF no se ve afectado por la apertura a largo plazo, aunque tiene efectos positivos temporales. En cuanto a los países en desarrollo, la apertura afecta negativamente la PTF, incluso cuando la variación del grado de apertura interactúa con los esfuerzos tecnológicos internos.

Palabras clave: Efectos indirectos de Conocimiento, Apertura Comercial, Crecimiento de la Productividad, Estimaciones de Datos Panel.

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1. INTRODUCTION

In most of the literature about technology spillovers, there are various well-known mechanisms of transmission of these spillovers. Thus, as pointed out by Hall, Mairesse, and Mohnen (2010), there are: (i) international trade in final goods, intermediate inputs and capital goods (COE & HELPMAN, 1995); (ii) external direct investment (DE LA POTTERIE & LICHTENBERG, 2001); (iii) migration of scientists, engineers, or their participation in workshops, seminars, and trade fairs (ALMEIDA & KOGUT, 1999); (iv) publications in technical journals and scientific papers, (ADAMS, 1990); (v) collaboration in research or international mergers and acquisitions (HALL, 1999); and (vi) foreign technology payments that include royalties, licensing fees, and patent sales (LOPEZ, 2008).

In this work, we focus on discussions on the first knowledge diffusion forms across countries (from the list above) and the international trade (COE & HELPMAN, 1995; COE et al., 1997; KELLER, 1998).

The theoretical assumption behind the international trade as a channel of technological diffusion is that "international trade of tangible commodities leads to an exchange of intangibles ideas" (GROSSMAN & HELPMAN, 1990), more specifically, these commodities, are understood as capital and intermediate goods. As Eaton & Kortum (2001), Grossman & Helpman (1991), and Caselli & Wilson (2004) stated, countries with more openness in machinery and equipment imports tend to take advantage from external knowledge efforts to improve their growth in total factor productivity (TFP).

Thus, the discussion about the link between trade openness and economic growth arises both theoretical models and empirical works. For example, Miller & Upadhyay (2000) found that a country's openness has a significant and robust positive effect on TFP. So, the question is: what the mechanism to lead openness to affect productivity growth? In order to answers this, the literature identifies the trade as a channel of knowledge diffusion among countries and consequently considers it possible to be a factor that influences the TFP growth.

However, there are also opposing visions such as those that empirical findings have shown up to now. In other words, empirical models show ambiguous results between trade openness and growth. For example, there is evidence of a positive relationship between both variables along with the idea that learning by doing is a key issue in the accumulation of human capital (LUCAS, 1993). Furthermore, a positive and significant correlation has been found between openness variable and long-run economic growth (ULAȘAN, 2012). Nonetheless, another work state that trade openness is negative for developing countries because these countries would produce goods of a very low learning rate (YOUNG, 1991).

Thus, there seems to be certain differences when we refer to technology spillovers between developing and developed countries. Moreover, Xu & Chiang (2005) argue that the literature has focused on industrialized countries and this, indeed, represents a serious limitation, due to the structural differences among both types of countries. Moreover, Ang & Madsen (2013) state that almost all available studies on knowledge spillovers have focused exclusively on the mature OECD countries. Hence, it is convenient to identify at least two groups of countries, since results obtained from a sample of mature industrialized countries do not necessarily extend to developing ones.

An important exception is a work by Coe, Helpman, & Hoffmaister (1997), who investigate the influence on the productivity of knowledge spillovers through the channel of imports from OECD countries to 77 developing countries. Their study focused mainly on the following aspect: knowledge spillovers through the channel of imports from North to South. However, they did not consider the effect on the productivity of domestic knowledge in developing countries, international knowledge transmission through channels other than imports, and knowledge spillovers among developing countries.

A recurring concern in the literature arises then, which is to identify the mechanisms of the trade process that lead gains on productivity and the way these are carried out. Empirical works have identified the transmission of international knowledge and innovation. As exposed by Easterlin (1981), Clark (1987), & Mokyr (2005), throughout history, the same technologies and production methods have often been employed around the world. Many cases include technology processes such as the steam engine, trains, the combustion engine, electricity, telecommunications, the internet, and radio transmission. Nevertheless, not all countries have effectively used the technologies and methods developed elsewhere.

The considered transmission mechanism or channel may be as import- or export-type. First, Ang & Madsen (2013) consider knowledge transmitted through the channel of imports. According to the endogenous growth models of Romer (1990); Grossman & Helpman (1991); and Aghion & Howitt (1992), horizontally and vertically differentiated intermediate inputs are the crucial determinants of TFP. For horizontally differentiated intermediate inputs, an increasing variety of them result in higher efficiency of economy-wide production. Vertically differentiated intermediate inputs possess different qualities, and their effectiveness in the final production depends on the number of times they have been improved. In both cases, the variety and the quality of intermediate inputs critically depend on Research and Development (R&D) investment, which suggests that TFP is a positive function of R&D stocks. Also, the variety and the quality of intermediate inputs are predominantly explained by cumulative R&D and, therefore, TFP reacts positively to knowledge stock accumulation. This line of reasoning suggests that the TFP of a country depends on its own knowledge stock and cumulative knowledge stocks embodied in imported intermediate inputs. Thus, technology is transmitted internationally by the import-weighted stock of knowledge.

There is a wide empirical literature on the link between TFP growth and international knowledge spillovers for OECD countries. Numerous empirical studies have investigated knowledge spillovers through the channel of imports: Coe & Helpman (1995); Engelbrecht (1997); Coe, Helpman, & Hoffmaister (1997, 2009); Keller (1998); Lichtenberg & De la Potterie (1998); del Barrio-Castro, Lopez-Bazo, and Serrano-Domingo (2002); Lumenga-Neso, Olarreaga, & Schiff (2005); Kneller & Stevens (2006); Madsen (2007, 2008a, 2008b); and Acharya & Keller (2009). Most of these studies find that domestic, as well as foreign knowledge, spillovers through imports are significant factors of TFP.

The second transmission channel, learning-by-exporting, in which firms learn to improve the quality of their products and production processes through contact with more advanced foreign competitors in global export markets, is another possible channel of technology transmission (BERNARD & JENSEN, 1999; CLERIDES, LACH, & TYBOUT 1998; FALVEY, FOSTER, & GREENAWAY 2004). Quite a few empirical studies have examined the relationship between growth and exports under the assumption that firms benefit from interacting with foreign customers because they impose higher standards than domestic customers (KELLER, 2004), and because trade induces more efficient use of labor and resources through learning (FALVEY, FOSTER, & GREENAWAY 2004). However, only a limited number of studies, such as Falvey, Foster, & Greenaway's (2004), have examined this channel of knowledge transmission.

However, there are not many models that reflect the fact that openness (as a single variable) could have some relation to with TFP growth in a technology-spillover sense. However, there is an exception given by Madsen (2009, 2008), who considers openness like a determinant of productivity growth. Additionally, it is not clear what connection this openness holds to a country's own productivity and technological efforts. Therefore, we start from the hypothesis that trade openness might be a channel of knowledge transmission but with the purpose of potentiating/optimizing internal efforts in order to impact on TFP growth.

The contribution of this study is summarized as follows. We associate openness to growth considering the possibility that openness is a carrier of technology spillovers. The aim of this dissertation is to find out the link between these two variables and prove the hypothesis mentioned above by proposing to go beyond those countries of OECD limitation and including a sample with developed and developing countries to test our hypothesis not just for high-income countries, but also for other categories of countries by income criteria. Furthermore, two additional objectives are proposed: first, to investigate the long-run and short-run effects of openness in TFP growth, using the cointegrated equations approach. And second, to verify the positive relationship between foreign knowledge stock like technology spillover on productivity growth, for a large sample, including developed and developing countries.

The rest of the present study is presented as follow: in section 2, related literature is reviewed, and we discuss the theoretical model of the endogenous growth framework behind the empirical models applied by the literature. We also present the main measurements of the variables used and discussions on them. Information on the database and methodological issues are presented in Section 3. The results and the sensitivity analysis are carried out in Section 4 and 5, respectively. Finally, Section 6 concludes this work. An appendix section is included to present additional tests for the estimated models.

2. THEORETICAL FRAMEWORK

2.1 Background

For a long time, the international transfer of technology has been recognized as an important source of growth and a likely determinant of the progress for developed and developing economies. However, until the arrival of the theory of endogenous growth, little systematic empirical analysis of this question had been carried out. According to Falvey et al (2002) in the 1960s and 1970s, several authors, including Gerschenkron (1962) and Kuznets (1973), began the early discussions about of the so-called advantage of 'backwardness'. This idea was focused on those countries with technological lag had the advantage that it would be possible to borrow new technology from more advanced countries (FALVEY, FOSTER, & GREENAWAY, 2002). Others, such as Abramovitz (1986), argued that to obtain such benefits, there must be other factors that affect the ability to adopt such technology, these factors being called 'social capacity'.

The literature identifies four mechanisms through which international interactions can enable the knowledge created in one country to implies changes in productivity and growth in others. First, the productivity of local resources can increase because the fact of a country to use intermediate and capital goods from overseas. Second, by increasing and improving communication channels between countries, they can encourage the more efficient use of domestic resources through cross-border learning of production methods, product design, organizational structures, and market conditions. Third, they can also help countries within the technological frontier to mimic the products of countries on the frontier. And fourth, the development of new technologies or the imitation of foreign technology can increase the productivity of a country (FALVEY, FOSTER, & GREENAWAY, 2002).

The comparison that typically arises in theoretical models about the discussion of the impact of trade on growth is between autarky and free trade. Literature not much-extended, examines how trade policy and changes in openness affect economic growth. These theories establish that the distancing from the autarky will give rise to positive knowledge externalities, without importance of the real volume of trade. Imports of any number of relevant products, however small, will give rise to positive spillovers (KELLER, 1998, 2000).

As pointed out by Falvey, Foster, & Greenaway (2002), within the scope of empirical evidence for international technology spillovers, there are also some other works to consider. For example, Coe & Helpman (1995) test the international spillover presence in a sample of 22 developed countries in the 1971-1990 period. They study up to what extent a country's productivity depends on domestic and foreign knowledge stocks, where cumulative R&D expenditures are used as a proxy for a country's knowledge stock. They constructed the foreign knowledge stock using the weighted sum of R&D spending accumulated by trading partners. Assuming the imports from a country act as the channel for knowledge spillovers, the bilateral import shares were used by as weights in the model. Also, the interaction between the weighted import share in the foreign knowledge stock with the volume of imports was allowed in order to examine the importance of the volume of trade and its distribution. They found that national and foreign knowledge stocks are important sources of productivity growth, although the former has a much greater impact on productivity in the larger countries. Smaller countries, it is argued, tend to be more open and to benefit more from foreign knowledge than larger countries. From these results, Coe & Helpman (1995) conclude that there is a relationship between productivity and stocks of internal and external knowledge, with the countries that obtain the most foreign knowledge and are the most open to trade.

In addition, Coe, Helpman, & Hoffmaister (1997) adapt the analysis mentioned in order to examine the extent of North-South R&D spillovers. They test the presence of knowledge spillovers through international trade of the 22 developed countries in the prior study for a sample of 77 developing countries in the 1971-1990 period. The method used has the exception that they use the mean of data in four five-year periods rather than annual data. It is further assumed by Coe, Helpman, & Hoffmaister (1997) that no R&D is undertaken in developing countries, so that no internal stock of knowledge is created. Foreign inventories of knowledge for developing countries are created using a weighted average of knowledge stocks of industrialized countries, with bilateral weights being the import of machinery and equipment as a measure of imports of capital and intermediate goods. As in Coe & Helpman's (1995) study, this import share weighted by the stock of foreign knowledge is also interacting with the volume of imports. They discovered that knowledge spillovers from the industrial north to the developing south are substantial. On average, a 1% increase in knowledge stocks in industrialized countries increases productivity growth in developing countries by 0.06%.

However, Keller (1998) compared those results with the ones obtained from the random designation of bilateral trading partners and found that regressions based on such simulated data generated on average larger estimated foreign knowledge spillovers as well as a better fit in terms of squared R. He concluded that Coe & Helpman's (1995) results may say little about the extent of the external effects of knowledge.

Furthermore, as pointed out by Ang & Madsen (2013), Keller (1998) states that a problem associated with spillover weighting arrangements is that they may not capture the channel through which knowledge is transmitted. He shows that randomly created import shares may create results that are even better than those based on explicit weighting. Keller (1998) finds that randomly generated import shares and no shares at all yield results similar to or stronger than those obtained by Coe & Helpman (1995). Keller (2000) argues that trade weights are not likely to be good measures of knowledge spillovers because total import streams may not be representative of trade in intermediate goods and because common trends and shocks in R&D and TFP may lead to a spurious relationship between the import-weighted knowledge stock and TFP. Acharya & Keller (2009) go beyond the implicit assumption of Coe & Helpman's (1995) approach that knowledge spillover elasticities are the same across all countries and, instead, focus on the individual transfer of technology through imports for six major OECD countries in which they find significant differences in the elasticity values.

In a more recent study by Falvey, Foster, & Greenaway (2004), a sample composed of 52 countries between 1976 and 1990 was used. They were two static models and two dynamic models. Their basic specification model correlated the per capita variation rate of the gross domestic product (GDP) against the variation rate of the foreign knowledge spillover variable, GDP per capita in 1965, the ratio of gross domestic investment to GDP, population variation rate, the percentage of people over 25 years old with secondary education in 1965, terms of trade variation rate index and Sachs & Warner's (1995) index of openness. In addition to this specification, they also modeled growth dynamically by introducing a lagged dependent variable.

That kind of specification was used to model movements from one steady state to another and to model the transitional effects of various policies, such as trade liberalization.

But, as the authors affirm, if we expect diffusion to have a differential impact on growth in the short- and long-run, then we may expect that specification to be misspecified. It is necessary to use a dynamic model, which has the advantage of allowing foreign knowledge spillovers to have both a short-run and a long-run impact on growth, which may be expected if full diffusion does not occur immediately.

Their main results can be summarized as follows. From the first static model, they found that most of the core variables are of the expected sign and significant. This was true for the ratio of investment to GDP, initial GDP, secondary schooling and, to a lesser degree, for population growth.

The coefficient, on the terms of the trade variable, tends to have the expected positive sign, but non-significant. Besides, the negative coefficients are inconsistent with the interpretation of this variable as knowledge spillover but are not extraordinary. On the second static model, Sachs & Warner's (1995) openness index was added. Its inclusion had little impact upon the size and significance of the core variables in the model, except for population, which falls in absolute size and becomes insignificant. The inclusion of the openness measure also has no impact upon the size and significance of the spillover variables. The coefficient on the openness measure is itself positive and significant.

This contrasts with Coe & Helpman (1995) and Coe, Helpman, & Hoffmaister (1997), who found negative coefficients on their measures of openness and suggested that openness has an impact on growth in addition to any indirect role in knowledge diffusion. Regarding the results of the dynamic models, they found coefficient values which were very close to those found in static models, both with and without the openness measure.

One observation made by Falvey, Foster, & Greenaway (2004) is important to be mentioned: the use of the imports to GDP ratio to measure openness raises the potential for multicollinearity between the openness and spillover variables. However, it should be noted that Sachs & Warner's (1995) measure has been criticized as a measure of "openness to international trade" by Rodriguez & Rodrik (1999), and it could well be capturing other aspects of openness.

Additionally, they state that the coefficients on the knowledge spillover variables in the first and second model imply that a 1% increase in the knowledge stock of the developed countries will, on average, raise growth in the developing countries by between 0.02 and 0.07 percent in the static model. The impact of knowledge spillovers found in the static model, therefore, are not too dissimilar to those found by Coe, Helpman, & Hoffmaister (1997), looking at the impact of spillovers on TFP growth.

The coefficients on the spillover variables in the dynamic model are interpreted as giving the short-run impact on growth of knowledge spillovers and suggest that a 1 % increase in the knowledge stocks of the developed countries will increase growth by between 0.01 and 0.06 percent.

An important implication of these results, like the authors indicate, is that openness affects growth through channels other than knowledge diffusion, a result not found by Coe & Helpman (1995) and Coe, Helpman, & Hoffmaister (1997).

Thus, these findings are a support, both theoretical and through empirical evidence, to develop the research proposal here. However, in the present study, the aim is to link the relationship between openness and productivity to capture technological implications by using different openness measure indexes that consider the trade policy. Next, we discuss some issues regarding theory and measures about the underlying factors that interfere and affect the main variables and concepts to be considered in the present investigation.

2.2 Theoretical models and measurements

2.2.3 Knowledge spillovers, openness and growth models

Following Coe & Helpman (1995), the theory behind the empirical equation presented by them and the one most used in the pertinent literature is based on theoretical models of endogenous growth theory in order to state that openness improves growth from focusing on exports to emphasizing imports of knowledge (ROMER 1990, 1992; GROSSMAN & HELPMAN 1991; RIVERA-BATIZ & ROMER 1991; BALDWIN & FORSLID 2000). We bring a brief review of such models.

In that sense, Helpman (1992) refers to the neoclassical theory of economic growth which has been mostly concerned with capital accumulation. When confronted with data, however, its central tenet could explain only a fraction of the variations in growth rates, while the rest was attributed to technical progress (SOLOW, 1957 and MADDISON, 1987).

Following what was commented by Madsen (2009), the theories described in Grossman and Helpman (1991) suggest that the efficiency of the production is affected positively by the quality of intermediate goods. Thus, labor productivity and total factor productivity (TFP) increasing since the new technology incorporated in imported intermediate goods or machinery makes imported products more productive. Consequently, trade will enhance growth only to the extent that a country trades with research-intensive economies. Similarly, Barro and Sala-i-Martin (1995) argue that imports give domestic producers access to a wider variety of capital goods, thus effectively enlarging the efficiency of production. Their model considers a two-country world, where the technologically less advanced country taps into the knowledge of the technologically more advanced country. Provided that the costs of imitation are lower than the costs of innovation, the less advanced country will catch up with the more advanced country.

However, other models predict that, under certain conditions, trade barriers may be good for growth, which is mainly discussed by Rodriguez & Rodrik (2000). Indeed, Grossman & Helpman (1991) and Matsuyama (1992) show examples in which countries that are sufficiently far behind the technological frontier may, through imports, experience a lower growth rate because they specialize in the production of traditional goods. Another related argument is that the local country needs a sufficiently high capacity to absorb the technology developed in the technologically more advanced countries (HOWITT, 2000). These models highlight the importance of using a sample of countries that are not too far away from each other technologically, as well as in terms of economic development, school level and, income level.

Therefore, the challenge of the present work is to take a sample which is as heterogeneous as possible to test the previous theoretical concepts and thus draw conclusions about these issues, in order to determine the interaction of foreign ideas trough imports with the internal knowledge efforts of the economies.

Thereby, for our purposes of theoretically supporting this study, we begin by taking the simplest case: suppose an economy which manufactures the final output Y from a variety of intermediate inputs. Given the measure of n available intermediate inputs, the production function of the final output is a linear homogeneous function of the employed inputs. Two stories appear to be common in the formulation of the production function. In one case, the inputs are horizontally differentiated. A simple formalization of this view takes the production function to be a symmetric constant elasticity of substitution function, with the elasticity of substitution being larger than one and every input to be manufactured with a unit of labor per unit of output. The result is that the output is proportional to aggregate employment of intermediates, or to total labor employed in the manufacturing of intermediates. And most importantly, the factor of proportionality is an increasing function of the measure of n available inputs (COE & HELPMAN, 1995).

The measure of available inputs expands because of R&D investment. Entrepreneurs who seek monopoly profits invest resources in the development of new intermediate inputs. In this event, the measure of available inputs is an increasing function of the country's cumulative R&D effort. It follows that the logarithm of TFP, as measured by $\ln Y - \ln L$ (where L stands for the available labor force and no capital is used in production), depends on a measure of cumulative R&D and the share of labor employed in manufacturing. In this model, labor is employed either in manufacturing or in R&D (COE & HELPMAN, 1995).

Thus, in the context of endogenous growth, the following model presented here is based on Grossman & Helpman (1991), and Romer (1990).[1] The model considers a small country endowed with a single primary factor, called labor. Households in this economy consume two final products, Y and Z, but the country specializes in the production of Y. Perfectly competitive firms manufacture this good using labor and a set of non-traded, horizontally differentiated, intermediate products. Total factor productivity in the final production increases with the number of available differentiated inputs. New varieties become available once they have been developed in the industrial research lab.

[1] This model is taken from the paper "Trade, Knowledge Spillovers, and Growth" (Grossman & Helpman, 1991) because of its theoretical relevance to the present study. Also, it served a base for the empirical approach proposed by Coe & Helpman's (1995) seminal work, whose equation has served in later developments on trade and spillover diffusion.

The production function for the good Y takes the form

$$Y = A_Y L_Y^{1-\beta} \left[\int_0^n x(\omega)^\alpha \, d\omega\right]^{\beta/\alpha}, 0 < \alpha, \beta < 1, \tag{1}$$

where A is a constant, L and $x(\omega)$ denote the inputs of labor and intermediates of type ω, respectively, to final production, and $n(t)$ represents the number of varieties available on the market at time t. The model takes the relative international price of good Y in terms of the import of good Z to be exogenous to the small country, and equal to one. Each unit of any intermediate is produced with one unit of labor. Therefore, its marginal production cost is equal to the wage rate, w. The intermediates are manufactured by a set (continuum) of monopolistic competitors, each of whom holds the patent to a countable number of varieties. The patents are, of course, the result of prior investments in R&D. It is well known that with a constant elasticity of substitution between varieties, each monopolist sets a price that is a constant mark-up over its marginal costs. This gives

$$p_x = {}^{w}\!/_{\alpha}. \tag{2}$$

With all available intermediates entering symmetrically into the production function, and all bearing the same price, each one is demanded to the same extent $x = x(\omega)$ at any moment in time. Using this fact, (1) can be simplified to

$$Y = A_Y L_Y^{1-\beta} X^\beta n^{\beta(1-\alpha)/\alpha}, \tag{3}$$

where $X=nx$ is the aggregate quantity of intermediates used, and the amount of labor embodied in these intermediates. If the intersectoral allocation of labor remains constant, as it will in a steady state, then Y grows at the rate $g\beta(1\text{-}\alpha)/\alpha$, where $g=\dot{n}/n$ is the rate at which new varieties of intermediates are being introduced to the economy. The model assumes that an entrepreneur can invent a measure dn of new varieties of intermediate goods per unit of time by applying (a/K)dn units of labor per unit of time to research. Parameter a is constant, while K represents the economy's instantaneous stock of knowledge capital.

Knowledge capital accumulates in two ways. First, during local product development efforts, researchers make discoveries that have wider applicability. They are unable to appropriate the benefits from these discoveries beyond what they earn from the patents on their new products. That is, the model assumes the existence of a spillover benefit from each domestic research project to the stock of knowledge capital in the research community at large.

This last fact together with the following feature lends us a theoretical foundation for our hypothesis, which we intend to test in the present study. In a second accumulation way, the model assumes that when residents of the small country interact with agents in the outside world, they gain access to a body of accumulated wisdom there, as well as to some of the new discoveries that are being made on an ongoing basis. The foreign contribution to the local knowledge capital stock increases with the number of commercial interactions between domestic and foreign agents. While knowledge can be acquired from the international community through channels that have nothing to do with business relations, it seems reasonable to suppose that the extent of the spillovers between two countries will increase with the volume of their bilateral trade.

In view of these alternative sources for the accumulation of knowledge capital, let $K(t) = F[n(t), T(t)]$, where $T(t)$ represents the cumulative volume of trade (exports plus imports) up to time t. As before, $n(t)$ is the number of available varieties, which also reflects the cumulative amount of domestic research that has taken place. We take $F(\cdot)$ to be increasing in both arguments and homogeneous of degree one. The latter assumption allows the model to define the 'intensive' function $\phi(\cdot) = F[1, T(t)/n(t)]$, such that

$$K = n\phi(T \,/\, n), \qquad \phi' > 0. \tag{4}$$

Entrepreneurs enter freely into R&D. The cost of developing a new product at a moment in time is aw/K. The benefit is υ, the value of a patent. Free entry implies $\upsilon = aw/K$. The patent yields an infinite stream of profits $\pi(t)$ from sales of $x(t) = X(t)/n(t)$ units at the price given in (2). The value of a patent at every moment is such that the dividend rate on this asset, π/υ, plus the rate of capital gain, υ/υ, provides a 'normal' rate of return. This 'no-arbitrage' condition implies

$$(1-\alpha)X\phi/\alpha a + \dot{w}/w - K/K = r, \tag{5}$$

where r is the instantaneous rate of interest on a consumption loan.

At this point in the model, it is necessary to highlight from the knowledge function assuming, for our purposes, the fact that in the accumulative process of knowledge capital exists the possibility that international trade, $T(t)$, affects it, while there also being some relation with the domestic factors, $n(t)$, which we have called internal efforts of the economy. That is, linking between trade and long-run growth of knowledge capital and economy productivity. The present research focuses on this main issue, to which we will return later. Then, advancing the model, the representative household maximizes an intertemporal utility function of the form

$$U_t = \int_t^x e^{-\rho(t-1)} \log u\,[c_Y(\tau), c_z(\tau)]\mathrm{d}\tau, \tag{6}$$

where $c_i(\tau)$ is the consumption of final good i at time τ. Here, $u(\cdot)$ represents instantaneous utility, which we assume to be non-decreasing, strictly quasi-concave, and homogeneous of degree one in its arguments. The household equates the marginal rate of substitution between the two final goods to the relative domestic price, $p = p_z/p_y$, at every moment in time. With international relative prices fixed at unity, we have $p = 1+z$, where z is the ad valorem rate of an import tariff (subsidy if negative) applied to good 2. Each household obeys an intertemporal budget constraint. In the aggregate, however, expenditure must equal national income plus tariff revenue, under the assumption that the country cannot borrow or lend internationally. Dynamic optimization requires that spending, E, evolve according to $\dot{E}/E=r-p$. The model is closed with the labor market clearing condition,

$$ag/\phi + X + L_Y = L, \tag{7}$$

where L is the constant and inelastic supply of labor. The three terms on the left-hand side of (7) represent employment in R&D, intermediate production and final production, respectively. Cost minimization in the production of good Y makes L_y/X a function of px/w, which, by the pricing relationship (2), remains constant through time. It follows that L is proportional to X, and the resource constraint can be written as

$$ag/\phi + b_L X = L, \tag{8}$$

for a constant $b_L > 1$.

Now the model supposes, at least for the time being, that $\phi(T/n)$ tends to a finite, long-run value, ϕ^*. Then the small economy approaches a steady state. So, from (6), $r = \dot{E}/E+p$, the aggregate budget constraint limits the growth of spending to the rate of growth of final output, or $\dot{E}/E = g\beta(1-\alpha)/\alpha$. Wages grow at this same rate, because total factor productivity in the final goods sector rises at this rate, unit production costs are constant (equal to the given international price) and relative input prices are constant as well. Finally, when ϕ approaches a constant, the rate of growth of knowledge capital converges on g. Therefore, in the steady state, (5) reduces to

$$(1-\alpha)X\phi/\alpha a = g + \rho. \tag{9}$$

In the steady state, consumption of each good grows at the same rate as final output. Therefore, the volume of trade grows at this rate, or $\dot{T}/T = g\beta(1\text{-}\alpha)/\alpha$. It follows that T/n will either shrink to zero, grow without bound, or tend to a constant in the long run. As a consequence, the model investigates whether α is larger than, smaller than, or equal to $\beta(1\text{-}\alpha)$, considering each of these possibilities in turn.

If $\alpha > \beta(1\text{-}\alpha)$, the relative importance of international trade spillovers as a source for the accumulation of domestic knowledge capital declines over time. In the long run, cumulative trade experience makes a negligible contribution to K in comparison with the contribution made by cumulative local research. The degree of openness cannot alter this inevitability, and so the trade regime has no effect on the long-run growth rate. Long-term growth is determined entirely by the available resources and by parameters describing tastes and technologies. Trade policy will, however, influence the economy along the transition path to the steady state. Policies that serve to expand the level of trade (i.e., an import subsidy or an export subsidy) promote contacts between local and foreign residents. Policies that contract trade, such as tariffs and export taxes, reduce the number of contacts. The former type of policy accelerates the rate of knowledge accumulation and growth, while the latter type retards learning and growth.

On the other hand, if $\alpha < \beta(1\text{-}\alpha)$**,** the ratio of trade volume to the number of varieties tends to infinity. There are two possibilities in this case. First, ϕ may converge to a finite limit. This would occur, for example, if $F(\cdot)$ had a CES form, with an elasticity of substitution between information from domestic and foreign sources in excess of one. Then the long-run dynamic equilibrium is the same as for an economy that does not learn from abroad, except that the limiting value for ϕ as T/n approaches infinity enters equations (8) and (9) in place of an arbitrary constant. In contrast to the case where T/n tends to zero, here the knowledge gained from trade contacts continues to drive growth in the long run. However, a marginal increase in the amount of trade (as might be affected, for example, by policy intervention) does not change the steady-state rate of innovation or growth. The full potential for trade contacts to contribute to the local knowledge stock will eventually be realized, regardless of whether policy stimulates or depresses the volume of trade. As in the previous case, a country that is more open to trade (i.e., has lower trade barriers) will converge more rapidly to the steady state, all else being equal.

A different type of long-run dynamics result when $\alpha < \beta(1\text{-}\alpha)$ and $\phi(\cdot)$ has no bound. Then, productivity in the research lab also increases without bound. This causes the rates of productivity growth and instantaneous utility to become unbounded. Since the household maximization problem is not well defined when utility is unbounded, the model excludes this case.

The final case to consider is an interesting one, mainly for our purposes here. This case arises when $\alpha = \beta(1\text{-}\alpha)$. Then, both the volume of trade and the number of varieties grow at the rate g in the long-run equilibrium. The ratio between the two approaches an endogenously determined, finite value. The model explores how trade policies affect the long-run growth rate in this case.

The model supposes first that ϕ were to increase exogenously. From this, the model leads to the conclusion that g must rise and X must fall. A reduction in ϕ has the opposite effects on the intermediate production and the long-run rate of technological progress.

Now, consider the effect of an opening of the economy, as represented by a reduction in the tariff rate, z, the homotheticity of preferences implies that consumption of good Z at given relative prices is proportional to the national income, Y. Factor proportions in the final good sectors remain constant (because $w/p_x=\alpha$), so Y is proportional to employment of intermediates, X, with a factor of proportionality that grows at rate g when $\alpha = \beta(1\text{-}\alpha)$. Therefore, the ratio of the cumulative trade volume to the number of varieties is proportional to X/g (Trade volume is the sum of exports and imports. This equals twice the imports, with balanced trade and an international relative unit price). A reduction in the tariff rate causes consumers to substitute c_z for c_y, given the national income, but X and thus Y could conceivably fall. It seems at first glance that T/n could move in either direction. But in fact, the long-run ratio of the cumulative trade volume to the number of varieties must rise. For, suppose not, then ϕ would decline. We have seen above that a decline in ϕ causes X/g to rise. But T/n cannot fall if both X/g rises and the relative price of imports decreases.

Now, the long-run effects of the reduction in the size of the barrier to trade are immediate. The ratio of the cumulative volume of trade to the number of varieties increases. This causes $\phi = K/n$ to rise, which acts like a boost to productivity in the research lab. Technical progress accelerates, and the economy grows more quickly.

Thus, as stated by Acemoglu (2009), the presence of international trade enriches the process of technology diffusion, since it introduces the possibility of the international product cycle, whereby technology diffusion goes together with certain products previously produced by technologically advanced economies migrating to less developed nations. Thus, with the support of this model – in the sense of theoretical support, since the present study is more based on the empirical literature –, we propose to test such idea for a wide sample of low, middle and high-income countries.

2.2.2 Measuring the Productivity

The theoretical discussion about income differences among countries recognizes that differences in capital per worker are a critical factor to determinate international income differences. However, the main difference is due to the part of output per worker that cannot be accounted for differences in capital per worker; that is, differences in *Total Factor Productivity* (TFP) (PRESCOTT, 1997). In that sense, TFP is understood as a residual. Based on the circular income flow model (HULTEN, 2001), TFP is the share of output not explained by the number of inputs used in the production process. Hence, its level is determined by how efficiently and intensely the inputs are utilized in such process.

Then, TFP refers to an overall measure of economic productivity, and this has some factors that affect its growth rate. According to Bauer (1990), into the production function approach, decomposing the TFP growth results in terms of technical efficiency and technological progress, and a term that depends on the degree of input-specific returns to scale and cost inefficiency. In this sense, based on the two first terms, this suggests that advances in both technological progress and technical efficiency increase TFP growth. However, the last term involves additional considerations.

Bauer (1990) states that when firms fails to produce at the lowest cost, the aggregate measure of input usage is a biased measure of actual input usage, since the observed input shares, not the cost minimizing input portions, are employed in the construction of this index. Thus, the observed measure of TFP growth is shown to depend on changes in production efficiency, technological progress, and a residual term that is present because of the bias introduced in the aggregation of inputs using observed input shares. On the other hand, within the cost function approach, the expression decomposes TFP growth in terms of returns to scale, changes in technical and allocative efficiency, technological progress, and a residual price effect term.

As stated by Xu & Chiang (2016), adopting the production function approach supposes that the output (Y) is produced by combining physical capital (K), labor (L) and knowledge capital (S). For instance, by a Cobb-Douglas production function, $Y=AK^{\alpha}L^{\beta}S^{\gamma}$, it is possible define TFP as

$$TFP = Y/K^{\alpha}L^{\beta}, \text{ and hence, } TFP = AS^{\gamma}, \tag{10}$$

where Y is the real gross domestic product (GDP), L the number of employed persons multiplied by annual hours worked, and K is the nonresidential capital stock, which is estimated using the perpetual inventory method for investment in nonresidential buildings and structures as well as machinery and equipment.

The term knowledge capital, S^{γ}, is composed by domestic and foreign effects, S^d and S^f, respectively. Following the empirical literature in the work made by Coe & Helpman (1995), we can express the domestic and foreign effects as R&D investments and, therefore, it is possible to define one first theoretical equation for TFP taking its logarithm form,

$$ln\, TFP_{it} = c_i + \gamma ln\, S_{it}^d + \rho ln\, S_{it}^f + \varepsilon_{it}, \tag{11}$$

where TFP_{it} is productivity in country i at time t; c_i is a country-specific fixed effect; $S^d{}_{it}$ is the domestic knowledge capital; and $S^f{}_{it}$ represents foreign knowledge spillovers; γ and ρ are the respectively TFP elasticities; and ε_{it} is an error term (NISHIOKA & RIPOLL, 2012).

Based on this approach, the idea here is to include another variable on that model and observe the connection between productivity and trade openness.

Thus, the TFP approach is a very usual measure in the literature to capture a contribution to growth from exogenous technological changes (CAVES et al. 1982; HARRIGAN 1997; KELLER 2002). As previously mentioned, such approach comes from the traditional neoclassical methodology to estimate the Solow residual (CRAFTS, 2003).

Based on that theory, Nishioka & Ripoll (2012) propose to estimate the TFP index using real value added (y_{cit}), labor compensation shares (σ_{cit}), gross fixed capital formation (k_{cit}), and total hours worked (l_{cit}) for each country *c*, industry *i* and period *t*. Hence, in logarithm form (with X, $x=lnX$ and $\bar{x} = \frac{1}{N}\sum_i x$; *N*), the calculation is:

$$tfp_{cit} = [y_{cit} - \bar{y}_{cit}] - \frac{1}{2}(\sigma_{cit} + \bar{\sigma}_{cit})[l_{cit} - \bar{l}_{cit}] - [1 - \frac{1}{2}(\sigma_{cit} + \bar{\sigma}_{cit})][k_{cit} - \bar{k}_{cit}]. \quad (12)$$

A few comments on this TFP index are relevant. First, the TFP index is normalized because, as shown in the equation above, it is constructed by expressing value added, capital and labor relative to their respective averages among the countries for each industry and year. This normalization is carried out without loss of generality, partially eliminating trends in absolute TFP levels. Second, the equation above uses an average labor share computed over two terms: labor share in country *c*, σ_{cit}, and cross-country average labor share in the whole sample, $\frac{1}{N}\sum_i \sigma_{cit}$. The normalization of the TFP index and this computation of labor shares impose a big amount of structure in the construction of TFP, which should help to reduce simultaneity issues in the estimation (KELLER, 2002). Finally, factor shares σ_{cit} are cost-based, since they are more robust than revenue-based shares in the absence of constant returns to scale.

Nevertheless, other authors are skeptical of the TFP approach and suggest alternative indicators for technological progress. For example, Li (2016) argues that not all aspects of technological changes are captured by TFP, and, indeed, may contain other non-technology factors, such as adjustment costs and measurement errors. Further, the TFP growth rate is useful for intertemporal comparisons of productivity for a given country or region at different time moments, but it is less useful for comparing the relative productivity between countries or regions (HULTEN et al, 2001).

Thus, Li (2016) proposes another technology indicator: the industry-specific R&D depreciation rate. This is proposed for an industry's international technological competitiveness, which requires two-time series for being measured: R&D investment and gross output. Moreover, notes that the rates of depreciation of business R&D depend on the level of technological progress of an industry and the degree of market competition (HALL, 1999). Such depreciation of business R&D capital is a consequence of its obsolescence over time that makes to have less contribution to a firm's profit. Therefore, a firm's R&D depreciation rate can show how much a firm can appropriate the return on its R&D investment. Also, this author states that supposing an industry in country A has a larger technological advantage than an equivalent industry in country B, the industry in country A has a lower R&D depreciation rate than its homologous in country B, in a trade openness context.

2.2.3 Knowledge Capital Stock

The economic theory has identified firms' R&D investments as one of the main sources of innovation and technological progress. Thus, it is important to review what the literature states about that. For instance, in an early work, Griliches (1979) uses a knowledge production function to connect the existing technical knowledge and all the present and previous R&D expenditures.

As pointed out by Huang (2007), R&D capital is the knowledge asset created by the investment in R&D yearly. Therefore, the stock of R&D capital is the accumulation of knowledge asset being a good proxy for this variable; R&D investment is potentially creative of new technology. Usually, to measure the R&D capital, stock is constructed by accumulating R&D expenditures based on the perpetual inventory method and an arbitrarily chosen depreciation rate with the range from 10% to 15%. The R&D stock at time *t* can be formulated by the previous R&D investment and the depreciated past R&D capital stock.

Thus, the domestic R&D stock or knowledge capital ${S^d}_{it}$ for country $_i$ at time t is computed using the perpetual inventory methods as follows:

$$S_{it}^{d} = (1-\delta)S_{i,t-1} + R_{it}, \tag{13}$$

where δ is the depreciation rate of knowledge obsolescence, and R_{it} is the real business R&D expenditure.

By foreign R&D stock side, the approach generally taken is to use shares of imports among pairs of countries as weights for the respective R&D stocks as follows:

$$S_{it}^{f} = \sum_j \frac{imports_{ijt}}{GDP_{jt}} S_{jt}^{d}, \quad (14)$$

where $imports_{ijt}$ correspond to those between recipient country *i* and source country *j*. This form is based on the approach of Lichtenberg & De la Potterie (1998), which reflects the intensity as well as the direction of international R&D spillovers. Thus, the stock of R&D that country *i* 'receives' from country *j* is country *j*'s R&D stock times the fraction of country *j*'s output that is exported to country *i*.

However, Coe and Helpman (1995) multiplied *imports* and S^f to capture the role of international trade. They argued that although S^f consists of import-weighted knowledge stocks, these weights are fractions that add up to one and, therefore, do not reflect openness. The weights in the weighting scheme of Lichtenberg & De la Potterie (1998) do not add up to one; however, they are influenced by import penetration, as argued above. Thus, the variable $imports_{it}\ S^f_t$ counts import penetration twice. So, *imports* and S^f are multiplied to investigate whether knowledge spillovers through the channel of imports influence growth in a nonlinear form (MADSEN, 2009).

Also, there is the possibility to use the domestic patent data as an information source of knowledge stock for the countries. This alternative way has an advantage over R&D expenditure because patent data are available for a long period since 1960 for almost all the countries considered in the present work. Madsen (2009) points out that, unfortunately, R&D data are only offered with good quality for the last two decades since 1996. Further, according with Griliches (1990), patent data are considered suitable indicators of new knowledge.

Thereby, we use the patent application data to build the domestic and external knowledge stock, following Madsen's (2009) approach and using the calculating methods explained above in order to compare with R&D expenditure data afterward.

2.2.4 Knowledge Spillovers

All types of knowledge share one essential feature, i.e., they are non-rival, which, according to Romer, means that the use of an idea by one producer to increase efficiency does not preclude its use by many others. In other words, the use of an item of knowledge in one application makes it be used by someone else without difficulty. Such as pointed by Acemoglu (2009), Romer's first model of endogenous growth (ROMER, 1986), introduced increasing returns to scale to physical capital accumulation. The justification for this was that the accumulation of knowledge could be considered a byproduct of the economic activities of firms. So, the idea here is, while the same unit of labor or capital cannot be used by multiple producers, the same knowledge can be used by many, potentially increasing everybody's productivity.

Another important implication of the non-rivalry of ideas is the market size effect. If someone has discovered an idea, it can be used as many times as possible and desirable, then the size of its potential market will be a crucial determinant of whether it is profitable to implement it.

Likewise, there is another property in the knowledge process: quasi-excludability. A good is excludable if it is possible to prevent others from using it. However, in this case, it will depend on both the nature of the knowledge itself and economic institutions governing property rights (ROMER, 2012).

Those two general characteristics suggest that spillover effects may be created in the process of innovation. This process mostly comes because of a desire to obtain some profit. Many relevant papers have researched about R&D performance and their implications for long-run economic growth (ROMER, 1990; GROSSMAN & HELPMAN, 1991; AGHION & HOWITT, 1992). However, as indicated by Grossman & Helpman (1990), these papers have focused on spillovers within the local research community of a closed economy or those that extend automatically to all researchers in the world economy.

The simplest models of endogenous technological change are those in which the variety of inputs used by firms increases (expands) over time because of R&D undertaken by research firms. In this chapter, we focus on these expanding input (machine) variety models. In this model, research (R&D) leads to the creation of new varieties of machines (inputs), and a greater variety of machines leads to greater "division of labor," increasing the productivity of final good firms. This can therefore be viewed as a form of process innovation. An alternative formulated and studied by Grossman and Helpman (1991a, b) focuses on product innovation. In this model, research leads to the invention of new goods, and because individuals like for variety, they derive greater utility when they consume a greater variety of products. Consequently, "real" income increases because of these product innovations.

Furthermore, Griliches (1992) states that, unless there are significant externalities, spillovers, or other sources of social increasing returns, it is unlikely that economic growth can proceed at a constant, undiminished rate into the future. That is a relevant argument to the present study, since we are interested in linking technology with growth, via the international trade channel.

2.2.5 Trade openness and policy implications

Economic theories indicate that increased access to foreign markets may influence the productivity of firms through several channels that can be broadly summarized as: increased competitive pressures, changes in market shares, increased access to technological improvements, and spillovers. Whether these effects are positive or negative depends, according to the economic theory, on the market structure and the type of trade instruments applied (TYBOUT, 2000).

The relative importance of international trade spillovers as a source for the accumulation of domestic knowledge capital declines over time. In the long run, cumulative trade experience makes a negligible contribution to capital in comparison with the contribution made by cumulative local research. The degree of openness cannot alter this inevitability, and so the trade regime has no effect on the long-run growth rate. Trade policy will, however, influence the economy along its transition path to a steady state. Policies that serve to expand the level of trade (i.e., an import or an export subsidy) promote contacts between local and foreign residents. Policies that contract trade, such as tariffs and export taxes, reduce the number of contacts (GROSSMAN & HELPMAN, 1990).

As suggested by Rodriguez and Rodrik (1999), the literature on openness and growth, as a key on the pursuit of the higher quality of data, has proposed the following empirical strategies: (1) building alternative indicators of openness (DOLLAR, 1992; SACHS & WARNER, 1995); (2) proving robustness by using a wide range of measures of openness, including subjective indicators (EDWARDS, 1998); and (3) comparing convergence experience among groups of liberalizing and non-liberalizing countries (BEN-DAVID, 1993).

For openness, some types of measures have been used. Ulașan (2012), for example, classifies openness measures into two general categories: trade volume index and direct trade policy measures. Typically, a first way to measure it is by expressing the ratio of exports plus imports to GDP. The problem with this form is that we define openness as the elimination or reduction of policy barriers to the international trade, instead of the volume trade, and this index is affected not only by the trade policy but also by other factors, such as the size of the country, the distance to business partners, transportation costs, global demand, etc.

As an alternative, direct trade policy measures, like tariffs barriers, are suggested as a better indicator to capture a country’s trade openness degree. However, intrinsic issues emerge when we attempt to summarize the tariff policy in one single variable, due to the impossibility of capturing all differences across countries’ trade policies.

To solve these problems, Ulașan (2012) proposes to compute three composite trade policy indexes consisting of weighted averages of tariff rates, non-tariff barriers, and black-market premium. Thus, weights are estimated using models where nominal and real trade volumes, as a share of GDP, are regressed on the initial level of income, country size and trade policy instruments.

Other previously mentioned authors, like Sachs & Warner (1995), suggest a dummy variable that classifies an economy as closed if it followed any one of these five criteria: (i) its average tariff rate exceeded 40%, (ii) its non-tariff barriers covered more than 40% of imports, (iii) it had a socialist economic system, (iv) it had a state monopoly of major exports, (v) its black-market premium exceeded 20% during either the 1970s or the 1980s. Therefore, as appointed by Rodriguez & Rodrick (2000), the variables most closely related to growth were the state monopoly of exports and black-market premium variable, while the other three variables (socialism, tariffs, and non-tariff barriers) did not seem to be more significant.

However, Warner (2003) contradicts the above statement, finding that the average unweighted tariff on capital and intermediate goods had a simple negative correlation. He also recalled the relevance of export marketing boards and exchange controls on limiting access to international trade.

On the other hand, Madsen (2009) uses two variables for a proxy to openness, tariff rates and import penetration. As already seen before, the theoretical literature gives more attention to the relationship between trade policies and income growth rather than the relationship between trade and growth (YANIKKAYA, 2003). Furthermore, there is no clear consensus as to what represents openness or what is meant by openness and trade liberalization (YANIKKAYA, 2003). In this regard, Rodríguez & Rodrick (2000) argue that import penetration is not a good measure of trade barriers and recommend the use of tariff rate instead, because imports is influenced by several factors other than trade barriers and, as such, may be a bad proxy for trade barriers (MADSEN, 2009).

However, in this study, we propose the standard trade openness indicators following the methodology described above. We will use the traditional openness form measured by trade volume imports plus exports to GDP.

2.3 Empirical works

In this section, a summary of the main empirical works is presented. Table 1 briefly shows information of papers investigated about areas related to the hypothesis defined by the present study. They are classified by author(s), geographical area coverage, the dependent variable studied by each work, explanatory variables, the estimation method used, the period of the sample and, finally, the results and main conclusions. In general, the results of these works reveal that foreign knowledge stock has a positive relation to productivity and, also, openness has short-run effects on TFP. However, these results have not established the link between openness and the domestic knowledge generation to affect productivity growth.

Table 1. Summary of Empirical Works

Authors	Coverage	Dependent Variable	Explanatory Variables	Estimation	Period	Results
Coe & Helpman (1995).	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Italy, Israel, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States, West Germany.	Total factor productivity.	Domestic R&D capital stock, and Foreign R&D capital stock weighted by a fraction of imports in GDP.	OLS with Cointegration approach.	1971-1990	Foreign R&D has beneficial effects on domestic productivity, and that these are stronger the more open an economy is to foreign trade. Moreover, the estimated rates of return on R&D are very high, both in terms of domestic output and international spillovers.
Coe, Helpman, & Hoffmaister (1997).	77 developing countries.	Total factor productivity.	Foreign R&D capital stock, Machinery and Equipment Imports from industrial countries in GDP in each developing country, the Secondary School Enrollment ratio.	FE	1971-1990	The R&D spillovers from North to South (as measured by the elasticity of TFP in the South with respect to R&D capital in the North) are substantial. On average, a 1% increase in the R&D capital stock in the industrial countries raises output in the developing countries by 0.06%.
Keller (1998).	21 OECD countries plus Israel.	Total factor productivity.	Domestic R&D capital stock, and Foreign R&D capital stock constructed by random import shares.	Monte-Carlo	1971-1990	It is not possible to argue that the pattern of international trade is important to estimate international R&D spillovers. Furthermore, positive international spillover effects in specifications which do not incorporate any pattern of international trade were found.

Miller & Upadhyay (2000).	Africa (19 countries), Caribbean, Central America, and North America (11), South America (11), Asia (16), Europe (20), and Oceania (4).	Total factor productivity.	Ratio of exports to GDP, terms of trade, local price deviation from purchasing power parity, and inflation rate.	FE	1960-1989	Increasing exports to GDP, improving the terms of trade, and lowering the real value of the domestic currency, generally benefits total factor productivity. An outward-oriented country experiences higher total factor productivity, over and above the positive effect of openness. Finally, human capital generally contributes positively to total factor productivity. For poor countries, however, human capital interacts with openness to achieve a positive effect.
Falvey, Foster, & Greenaway (2002).	5 OECD countries and 52 developing countries	GDP per capita growth rate.	Foreign knowledge spillover, the Sachs and Warner (1995) index of Openness, Terms of trade index, the ratio of gross domestic investment to GDP, Population.	GMM	1976-1990	The specifications that depend upon the level of imports result in positive coefficients. The results from the specifications that do depend upon the level of imports suggest that a 1% increase in the knowledge stock of the developed countries can increase growth in the developing countries by between 0.01 and 0.07 percent in the short-run.
Madsen (2009).	16 OECD countries	Total factor productivity.	Domestic Knowledge capital stock, and Foreign Knowledge capital stock constructed by application patent. Openness measured	Generalized Least Squares (GLS).	1870-2006	The estimated coefficients of tariff are generally of low statistical significance and with conflicting signs, which suggests that there is no clear direct relationship between growth and tariffs when knowledge and research intensity are allowed for in the estimates. The estimated

			by Tariff and propensity to import (m).			coefficients of m are statistically insignificant, while the estimated coefficients of Δm are positive and mostly statistically significant. These results suggest that openness does not have any direct permanent growth effects but may have direct temporary positive growth effects.
Krammer (2014).	47 developed and transition countries	Total Factor Productivity	Knowledge Spillovers via imports, FDI, Foreign Patent, Licensing of technologies.	FE	1990-2009	This paper finds that trade remains the dominant factor behind productivity and technical progress. It supports the absorptive capacity story (positive and statistically significant coefficient for the interaction between domestic R&D stock and spillover variable). and free trade benefits (the more open a country is, better advantage of these spillovers it can take).
Fracasso & Vittucci (2015).	24 developed countries	Total Factor Productivity	Domestically and Foreign produced R&D stock, Human capital stock, Trade measured by import-GDP ratio.	Nonlinear Least Squares (NLS).	1971-2004	This study finds evidence that trade patterns positively affect the international transmission of knowledge, in particular when bilateral trade flows are considered.

Source: Own elaboration

3. DATA AND METHODOLOGY

3.1 Database

The dataset covers the period from 1969 to 2014 and comprehends 58 countries: Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, Switzerland, Chile, China, Colombia, Costa Rica, Germany, Denmark, Dominican Republic, Ecuador, Egypt, Spain, Finland, France, United Kingdom, Greece, Guatemala, Hong Kong, Honduras, Indonesia, India, Ireland, Iran, Iceland, Israel, Italy, Japan, Kenya, Republic of Korea, Morocco, Mexico, Malaysia, Nigeria, Nicaragua, Netherlands, Norway, New Zealand, Panama, Peru, Philippines, Portugal, Paraguay, Romania, Singapore, Sweden, Thailand, Tunisia, Turkey, Uruguay, United States, Venezuela, and South Africa.

Data on TFP, GDP, trade and national accounts, and human capital (hc) were obtained from the Penn World Table 9.0 (PWT 9.0). Data on patent applications by resident and non-resident were obtained from the World Bank (WB) Database, which uses the World Intellectual Property Organization (WIPO) as source. All data but labor – which is measured in millions of worked hours by employees – are in US$ million at constant 2011 prices and transformed into natural logarithm form (ln), except for TFP and openness, which are expressed as indexes. From the previous descriptions, Table 2 specifies the variables used in this study, the expected sign and the data source.

Table 2. Description of the Main Variables of the Model

Variable		Description	Expected sign	Source
Explained Variable	*tfp*	Total Factor Productivity Index		PWT 9.0
Explanatory Variables	*O*	Openness Index	+/-	PWT 9.0
	Sd	Domestic Stock of Knowledge	+	WIPO/WB
	Sf	Foreign Stock of Knowledge	+	WIPO/WB
	hc	Human Capital Index	+	PWT 9.0

3.2 Empirical Strategy

The empirical strategy followed in this work is based on the data panel methodology. The estimates make through Fixed Effect (FE) or Random Effect (RE). Furthermore, the Instrumental Variable (IV) in Two-Stage Least Square (2SLS) and Generalized Method of Moments (GMM) estimators, are used to solve possible endogeneity effects of country productivity on the trade variable. Lastly, estimate via robust errors is used to obtain correct standard errors through heteroskedastic panels.

Based on the specification of Coe & Helpman (1995) and Madsen (2009), the first basic model to be estimated is:

$$\Delta ln\ tfp_{it} = \beta_0 + \beta_1^{d}\left(\Delta ln\ S_{it}^{d}\right) + \beta_2^{f}\left(\Delta ln\ S_{it}^{f}\right) + \beta_3^{o}(O_{it}) + \beta_4^{od}(O_{it})\left(\Delta ln\ s_{it}^{d}\right) + \beta_5^{hc}(hc) + \beta_6^{hc^2}(hc^2) + \beta_7^{I}(I_{it}) + \varepsilon_{it}, \qquad (15)$$

where *tfp* is total factor productivity, S^d is the domestic knowledge capital, S^f is the foreign stock of knowledge spillovers through the trade channel, *O* is the level of trade openness, $O(S^d)$ is the openness with domestic knowledge stock interaction, *hc* is human capital index, *I* is a vector of selected instrumental variables, and ε is an error term. Δ is the first difference operator, the subscripts *i* and *t* signify country and time, respectively, and β is the respective coefficient.

The last variable, $O(\Delta \ln S^d)$, is constructed in order to test the hypothesis that openness affects internal efforts in the long run. It is expected to be positive if the trade of product varieties between advanced and less developed countries improves intellectual and innovative activities (absorptive capacity). The opposite case could be evidence for supporting the argument of Rodríguez & Rodrik (2000), who state that the presence of some trade barriers may be good for the internal development of knowledge and technology.

Additionally, we also are interested in observing the short-term effects of openness on productivity. For this purpose, we include two more variables: openness in first difference, ΔO, and interaction with domestic knowledge, $\Delta O(\Delta \ln S^d)$. Thus, we have a second equation to estimate:

$$\Delta \ln tfp_{it} = \beta_0 + \beta_1^d(\Delta \ln S_{it}^d) + \beta_2^f(\Delta \ln S_{it}^f) + \beta_3^o(\Delta O_{it}) + \beta_4^{od}(\Delta O_{it})(\Delta \ln s_{it}^d) + \beta_5^{hc}(hc) + \beta_6^{hc^2}(hc^2) + \beta_7^I(I_{it}) + \varepsilon_{it}, \quad (16)$$

Two brief comments are needed at this point. First, it is not possible to include both variables of openness in the same equation, for methodological reasons. That is because the estimation would present collinearity, since we consider openness to be probably endogenous and we use openness lagged and in differences as instruments in order to exclude such endogeneity.

Second, the first difference operator (Δ) is included to capture the influences of economic cycles. About this, the literature in micro studies has generally shown a positive association between increased exports and productivity growth. However, the relationship between imports and productivity growth is often negative. That observed pattern is likely to be since countries tend to export goods in which they have a comparative advantage and to import goods in which they do not, which generates inability to distinguish between the expected positive effect of imports on TFP growth in the long run and the fact that imports are drawn to low productivity sectors where a country does not have international advantage. In addition, the observed relationships could also be explained by the well-known pro-cyclical nature of productivity growth: this tends to be higher when output is growing and falls during recessions or low-growth periods. Therefore, if greater import penetration is accompanied by a contraction of the domestic industry, productivity growth is expected to fall as well. This is known as the simultaneity problem (HARRISON, 1991).

To solve this issue, some authors, such as Quah and Rauch (1990), use trade shares as a proxy for openness to decompose the short- and long-run effects of openness on economic growth and take out the trend component of the series. They find that most of the observed positive relationship between openness and growth is due to short-run cyclical fluctuations.

For the selection of the RE or FE method, the Hausman test will be performing. The null hypothesis of this test states that both estimates are not systematically different and, therefore, the most indicated estimator is that of random effects (BALTAGI 2008).

Furthermore, dynamic panel data estimation is associated with Arellano & Bond (1991) and Arellano & Bover (1995), in which the lagged dependent variable is included as a regressor. The use of dynamic models for panel data is justified by the fact that many economic series are dependent on their past values. In this case, it is possible that the country's productivity depends on the productivity of the past period. The inclusion of this variable, therefore, can capture the dynamics of production growth in a more robust way.

The Arellano & Bond (1991) estimator of the Generalized Moments Method (GMM) instrumentalizes the explanatory variables in a difference in which they are not strictly exogenous with their available lags in the level. However, in this first difference GMM estimator, the available level gaps may be weak instruments for non-strictly exogenous variables (ARELLANO & BOVER 1995).

To solve the problem of weak instrumentalization, Arellano & Bover (1995) and Blundell & Bond (1998) developed System GMM, which adds GMM in difference, the original level equation, thus increasing efficiency due to the presence of more instruments. These estimators can be used in posterior extensions of the present work.

The choice of the model makes through the Sargan-Hansen test, which is applied by both the IV and GMM models. The null hypothesis says that the overidentifying assumptions are valid. That is, it tests the validity of the used instruments.

3.3 Descriptive statistics analyses

The descriptive statistical analysis of the data is now presented. Table 3 shows the mean and standard deviation of the variables used in the model, organized by group of countries, and each variable denotes Domestic Knowledge Capital, S^d_{it}, Foreign Knowledge Spillover, $S^f_{it,}$ and Openness, O_{cit}. Moreover, the last column presents the percental distribution of the sample by country category.

Due to characteristic differences between countries, which may affect the knowledge transmission among developed and developing economies through intermediate varieties imports, we use a classification suggested by Ghimire, Kapri & Rahman (2018). According to the World Bank convention, countries with per capita income (in US dollars) below 1,025 are defined as lower-income economies, per capita income between 1,025 and 4,035 defines lower-middle-income economies, upper-middle-income economies have per capita income between 4,035 and 12,475, and countries with per capita income above 12,475 are defined as high-income economies.

Table 4 shows the correlation matrix of the main variables in the present study. We also include the control variable and used instruments in section 4. Such variables are explained by solving endogeneity problems of openness.

The most important object here is to observe any possible collinearity relation between the explanatory variables. However, as the table shows, this problem does not seem to exist because the correlation coefficients do not exhibit high values, close to one (1). In addition, the correlation coefficient among the explanatory and the explained variable, TFP, states how strong the relation between them is. In this case, the Foreign Knowledge Stock, *Sf*, has the strongest correlation, in addition to showing positive sign, followed by the Unemployment Rate Growth and Openness in First Difference, with negative and positive signs, respectively.

Additionally, Figures 1 and 2 show the scatterplot for TFP and Openness. In the first figure, we can observe a positive trend for the annual average variation. However, there is a clear presence of outliers in both directions, as the case of Hong Kong or Singapore, which are countries with a very high openness volume and, at the same time, increasing productivity rates. In contrast, we find that Iran is in a very opposite situation, with a negative productivity growth rate and the lowest rate for openness in the sample.

In the second figure, nevertheless, there seems to be no clear relationship between the TFP annual average growth rate and the annual average of the openness level. This could suggest that TFP and Openness are more closely linked in the short-run, which is also supported by the coefficient between $\Delta ln\ tfp$ and ΔO presented in the correlation matrix.

Table 3. Descriptive Statistics of the Main Variables

Countries Category	Domestic Knowledge		Foreign Knowledge		Openness		Percent
	Mean	***Std***	***Mean***	***Std***	***Mean***	***Std***	
High-income	10.180	1.648	12.778	0.977	0.526	0.309	29.82%
Emerging-income	7.368	2.902	11.643	1.101	0.763	0.928	21.05%
Middle-income	6.360	2.024	10.444	1.072	0.614	0.373	33.33%
Low-income	3.019	2.044	9.357	1.036	0.657	0.298	15.79%

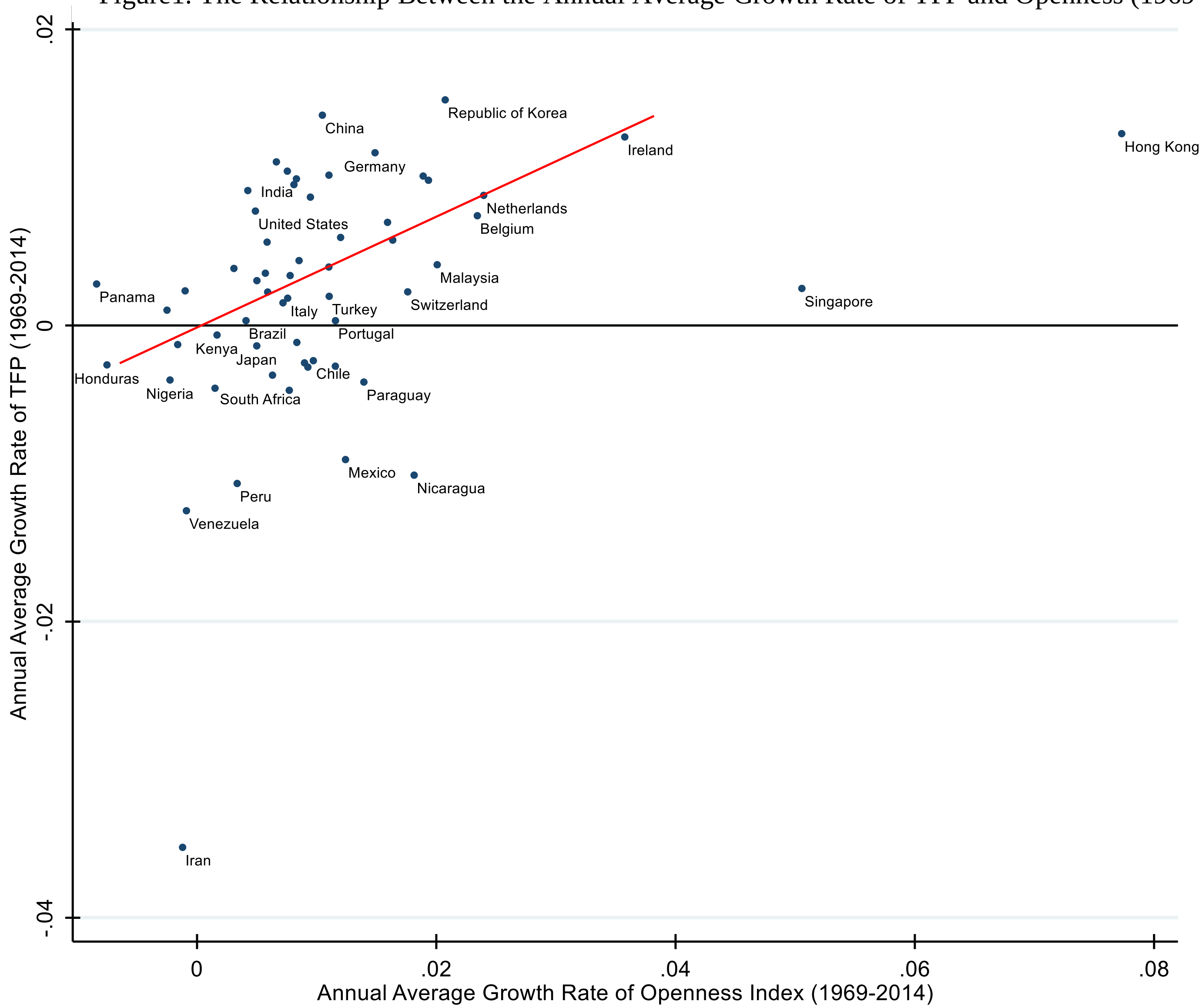
Source: Own elaboration

Table 4. Correlation matrix of the interest variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Δ*ln tfp*	1														
2 Δ*ln Sd*	-0.0128	1													
3 Δ*ln Sf*	0.4228	0.0177	1												
4 *O*	0.0178	0.0834	0.0781	1											
5 Δ*O*	0.2237	0.077	0.3418	0.1744	1										
6 *O**Δ*Sd*	-0.0244	0.8006	0.0194	0.2477	0.1602	1									
7 Δ*O**Δ*Sd*	0.0118	0.3956	0.0669	0.1562	0.2798	0.6826	1								
8 *hc*	0.1021	-0.0787	0.0096	0.0395	0.0082	-0.042	-0.011	1							
9 *hc2*	0.1006	-0.0772	0.0038	0.029	0.0035	-0.047	-0.0166	0.9916	1						
10 *ln pop*	-0.0116	0.0311	0.0059	-0.4207	-0.052	-0.0629	-0.0541	-0.0281	-0.0133	1					
11 *pop den*	0.0221	0.0759	0.0327	0.7367	0.1421	0.2363	0.1567	0.0163	0.0158	-0.2185	1				
12 *unemp rate*	-0.0799	-0.016	-0.0817	-0.1384	-0.0104	-0.0519	-0.0281	-0.0701	-0.0864	0.0292	-0.1867	1			
13 Δ*unemp rate*	-0.2399	0.0369	-0.2929	-0.0324	-0.024	0.0345	0.0065	0.0084	0.004	0.0122	-0.0159	0.1977	1		
14 *inflation*	-0.0969	-0.0304	-0.0575	-0.0533	0.0023	-0.0185	-0.0084	-0.0543	-0.0555	-0.0057	-0.0224	0.0657	0.0908	1	
15 Δ*agr gdp*	-0.0196	-0.0224	-0.0933	0.0242	-0.0213	0.0025	-0.0078	0.0699	0.0731	-0.0214	0.0197	0.0562	0.0179	-0.0506	1

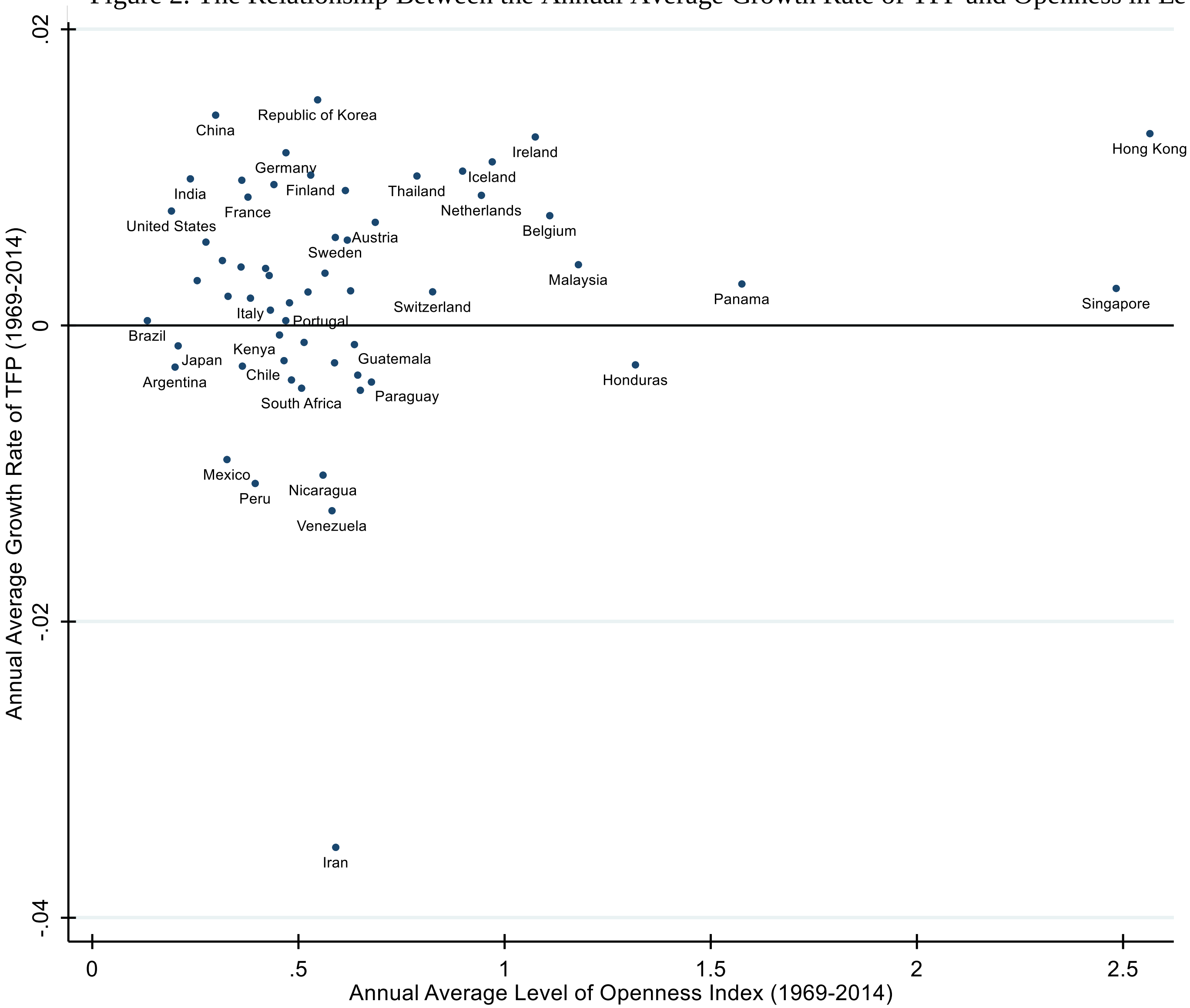
Source: Own elaboration

Figure1. The Relationship Between the Annual Average Growth Rate of TFP and Openness (1969-2014)



Notes: Each point represents a country of the sample. The red line is a trend line around observations. The annual average growth rate measures the variation of TFP and Openness index between 1969 and 2014. Source: Own elaboration.

Figure 2. The Relationship Between the Annual Average Growth Rate of TFP and Openness in Level (1969-2014)



Notes: Each point represents a country of the sample. The annual average measures the growth rate of TFP and the Openness index in level between 1969 and 2014.
Source: Own elaboration.

Below is presented a brief analysis of the main variables time series. Figures 3, 4 and 5 show the performance of variable averages along the considered period for high-income countries.

Figure 3. TFP
High-income

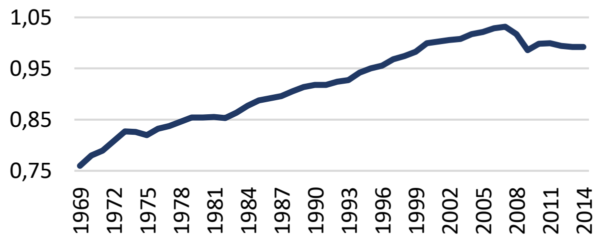


Figure 4. Domestic Knowledge Stock
High-income

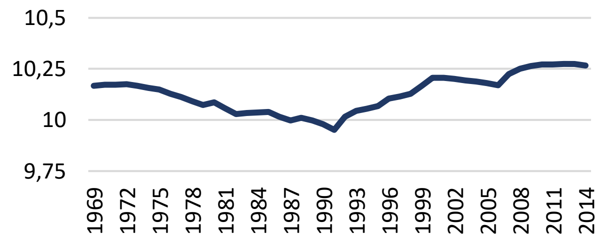
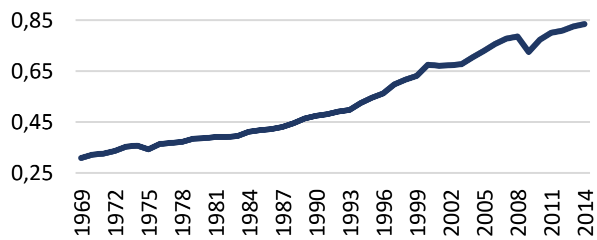


Figure 5. Openness
High-income



Note: Domestic knowledge stock measured as patent by resident, in logarithmic form.

The TFP average for high-income countries increased in an almost constant rate until 2008. After this year, the decline in TFP was probably due to the financial crisis, which had a negative impact on the world economy. Moreover, it is important to highlight the first years of the period, from 1969 to 1973, when these countries experimented an exceptionally high TFP growth rate. It is possible that the petroleum crisis registered after 1973 and the increment in commodity prices affected the productivity of these countries.

Although the number of patent applications in United States, Japan, Germany and Canada increased at meaningful growth rates for all the period, such rate was rather irregular in most of the European Union, with fail periods followed by more intellectually productive years. On average, however, this variable had a constant behavior for this category of countries.

Trade has increased in high-income countries, especially after the 1980s, maybe because of the larger liberalization policy applied since those years and more trade agreements established by those countries (the European Union, for example). It is relevant to say that such boom in openness was more marked out in European countries like Belgium, Netherlands Switzerland, Austria or Denmark, that present both the highest levels and highest growth rates for this variable along the whole period. Conversely, other high-income countries, such as United States, Japan or Australia, show the exact opposite regarding trade openness, with the lowest levels and rates.

Figures 6, 7 and 8 show the performance of variable averages along the considered period for upper-middle-income countries.

Figure 6. TFP
Emerging-income

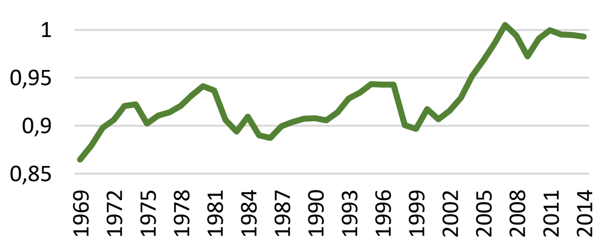


Figure 7. Domestic Knowledge Stock
Emerging-income

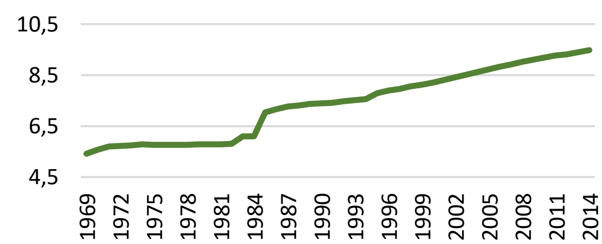
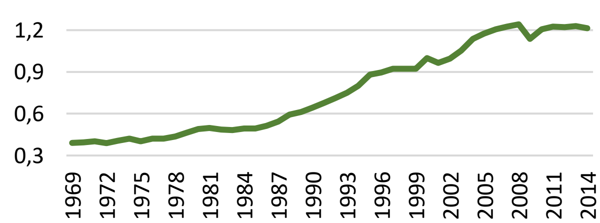


Figure 8. Openness
Emerging-income



Note: Domestic knowledge stock measured as patent by resident, in logarithmic form

In contrast with the latter category of countries, the TFP average of the upper-middle-income, also known as emerging-income, is very irregular but equally increasing, particularly during the 2000s, because of the spectacular growth of China in these years. In general, this category is very affected by the high rates of Chinese performance. Similarly, after the 2008 financial crisis, the series experimented a temporary decrease.

The domestic knowledge stock, in terms of patent applications in these countries, increased extraordinarily after the 1980s, especially in the Asian emerging economies: China, Hong Kong, Malaysia, India and Indonesia. However, other countries such as Korea, Brazil, Mexico and South Africa, have had a more constant rate in knowledge creation measured by patents. In fact, for the latter two countries, this variable has decreased.

Like the volume of trade carried out by high-income countries, this variable grew considerably after the 1980s, probably because Hong Kong, Singapore, Malaysia, and Korea opened to international trade in an extraordinary way. The rest of the emerging countries had a more moderate growth, with South Africa and Brazil experiencing fewer variations over time.

Figures 9, 10 and 11 show the performance of variable averages along the considered period for lower-middle-income countries.

Figure 9. TFP
Middle-income

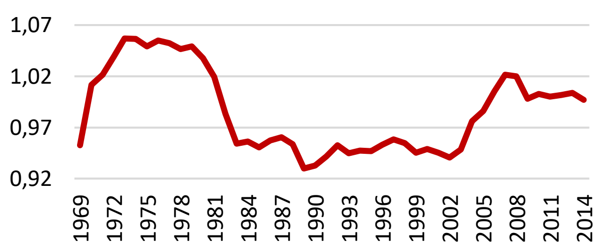


Figure 10. Domestic Knowledge Stock
Middle-income

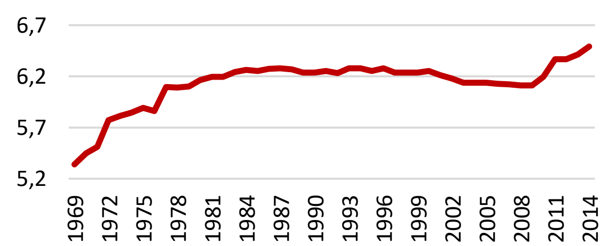
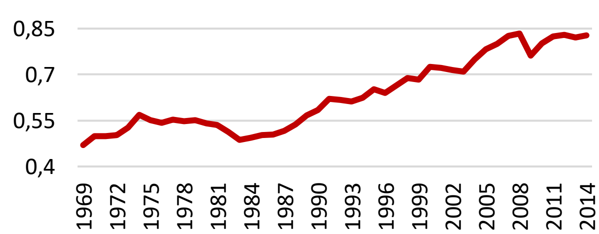


Figure 11. Openness
Middle-income



Note: Domestic knowledge stock measured as patent by resident, in logarithmic form

In the case of the lower-middle-income category, also called developing economies, one can observe that, on average, these countries suffered a significant decrease during the 1980s and 1990s, which have been often termed the lost decades in the literature, especially in Latin-American economies, with Venezuela and Peru being the countries with the starkest decrease in productivity. Most of these countries lived the so-called debt crisis. It was a financial crisis that originated in the early 1980s, when Latin-American countries reached a point where their foreign debt exceeded their earning power, and they were not able to repay it, which could affect their productivity.

The average of domestic knowledge in these countries has had barely any variation. Costa Rica, Panama, and Ecuador have the lowest level for the entire period, while Romania, Argentina, and Greece are the most intellectually productive countries for this category. On the other hand, Thailand and Egypt exhibited the highest growth rate.

Openness for lower-middle-income countries also presented an upward trend after the 1980s, but in this case, there is an economy that is well above the average. Panama, due to its economic nature, has an external sector that is greater than the internal, which arguably makes the country be considered an outlier in its category. Removing Panama from the analyses, Thailand and Romania are the countries with higher openness growth rates. Argentina and Colombia have the lowest levels of this variable. Iran is the only country that is less open currently than in the past.

Figures 12, 13 and 14 show the performance of variable averages along the considered period for low-income countries.

TFP for these countries is mainly decreasing throughout the period. Only after the 2000s did productivity stop this downward trend and began to improve slightly. Nigeria, Nicaragua, Panamá, Bolivia, and Philippines were the countries that suffered the highest drop in productivity between 1975 and 2000. It is curious that, unlike what happened in the previous category, the 2008 financial crisis seems to have had a less negative impact in terms of TFP growth rate on these countries. This finding is perhaps associated with the fact that these countries are less connected with the international finance market.

Figure 12. TFP
Low-income

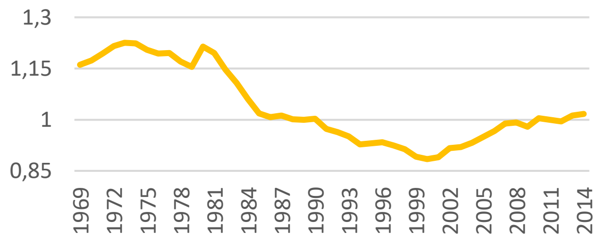


Figure 13. Domestic Knowledge Stock
Low-income

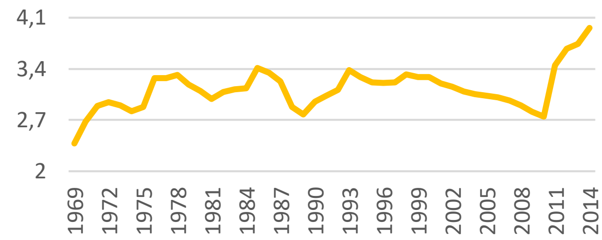
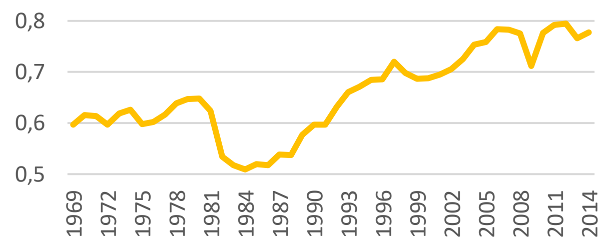


Figure 14. Openness
Low-income



Note: Domestic knowledge stock measured as patent by resident, in logarithmic form

For almost all the period, this variable was kept constant in the Philippines and Guatemala, and with subtle variations for the rest of the sample countries. However, Kenya is an exception in this trend, presenting the highest growth rate, going from practically zero to a value well above the average level.

The trade variable average has a very similar behavior to the same variable in the other categories of countries.

3.4 Unit Root Test

The variables contained in Equation (10) need to be either stationary or, if not, need to form a cointegrating relationship, provided that the dependent variables are stationary. Table 5 shows the unit root tests of Levin et al (2002), Harris & Tzavalis (1999) and Breitung (2000). According to this unit root tests, all the variables included are stationary. The only exception is the Trade variable in level. The rest of the variables are in years variation. Additionally, the Im-Pesaran-Shin (2003) can be tested with unbalanced panel dataset just because our panel dataset is balanced; it is not used here.

Table 5 Unit Root Test [2]

Variable	*Levin-Lin-Chu*	*Harris-Tzavalis*	*Breitung*
Δln tfp	-8.2697 (0.000)	-10.1964 (0.000)	-11.8750 (0.000)
Δln Sd	-7.4209 (0.000)	-10.5117 (0.000)	-10.0121 (0.000)
Δln Sf	-9.7595 (0.000)	-17.0461 (0.000)	-10.4877 (0.000)
O	6.1800 (1.000)	6.7221 (1.000)	14.9197 (1.000)
ΔO	-6.5893 (0.000)	-15.1164 (0.000)	-9.2139 (0.000)
O*sd	-8.3837 (0.000)	-19.9878 (0.000)	-8.1440 (0.000)

In all these three tests the null hypothesis is the presence of unit roots into the panels. For the most variables considered, we can reject the null and, therefore, such variables are valid to be regressors of productivity growth as proposed by equations (15) and (16).

Although the variable Openness (O) in level is not stationary, it is included in the estimations so that its long-run relationship with productivity growth, as suggested in the related literature (MADSEN, 2009, for example), can be observed. For that, we need to estimate cointegrated equations.[3] According to Coe and Helpman (1995), the basic idea of cointegration is that, if there is a long-run relationship between two or more trended variables, a regression containing all the variables – the cointegrating equation – will have a stationary error term, even if none of the variables taken alone is stationary. If the error term is not stationary, the estimated relationship may be spurious (GRANGER & NEWBOLD, 1974).

Most studies of the determinants of total factor productivity or output have been based on a change, rather than a level, specification because differencing was thought necessary to avoid the spurious correlation problem when estimating a relationship between trended variables. The disadvantage of a change specification is that the information embodied in the long-run relationship between the variable levels is discarded by differencing. The advantage of the cointegrating approach, in which the relationship is estimated in level terms, is that it exploits rather than discards

[2] The numbers in parentheses are *p*-values. The critical values for the *Levin-Lin-Chu* and *Breitung test* are approximately -2.24 (5%) and -2.40 (1%). The $Z\sim t$ statistic is distributed as $N(0,1)$ under the null hypothesis that the variable contains a unit root.

[3] For more information about cointegration see Engle and Granger (1987), Stock (1987) and Cuthbertson et al. (1992).

the relevant information about shared trends that is embodied in the levels data (COE & HELPMAN, 1995).

Cointegrated equations have attractive econometric properties. The most important is that, as the number of observations increases, OLS estimates of the cointegrating equation converge on the true parameter values much faster than in the case where the variables are stationary, i.e., they are 'super consistent' (STOCK, 1987). Cointegration techniques have been widely applied to time-series data. It seems natural to test for international R&D spillovers on panel data, however, and the relatively small number of time-series observations that are available for any single country makes the use of a panel data set particularly attractive (COE & HELPMAN, 1995). So, following this approach, we estimate our equations on panel data and present in the appendix the Wooldridge test for autocorrelation (2003), which has the null hypothesis that no first-order autocorrelation is there.

3.5 Endogeneity of Trade variables

De Castro (2013) states that one of the great challenges of the literature on productivity is to address the issue of *simultaneity*, which occurs when an explanatory variable is determined along with the dependent variable in econometric models that seek to show the causality relationship between the possible explanatory factors, e.g., institutions and per capita income. The author points out that, based on the main empirical studies on the subject, the richest countries are generally able to maintain stronger and more stable institutions. This means that we must be aware of the problem of reverse causality in studies that relate institutions and economic development.

Therefore, since trade is approached from the point of view of policy decisions in this study, that is, protectionism or not, trade can be treated as an institution, so similar problems of endogeneity[4] can arise in the world of international trade.

[4] In econometric models, an explanatory variable (x_j) is considered endogenous when it is correlated with the error term of the equation (u) (WOOLDRIDGE, 2002).

In addition to the issue of simultaneity, according to De Castro (2013), other factors could generate endogeneity, thus damaging the quality of the econometric estimates in this type of study. They are: *omission of variables*, since many factors besides institutions can affect countries' income level or productivity growth, generating a tendency to overestimate the effect of institutions (trade, in our case); and *measurement error*, since the variables used to measure the institutions are always proxies that are chosen with some degree of subjectivity and that, therefore, may contain measurement errors.

As described before, trade is measured by an index of imports plus exports, but this really is a proxy of openness, and thus two issues arise immediately. First, such variables of trade need to be exogenous, and second, the proxy condition of the trade variable implies an error of measurement which is also a source of endogeneity.

Regarding this matter, Madsen (2009) points out several instrumental variables (IV) for trade in order to solve endogeneity issues, namely: population density (ratio of population and the land area); time dummies; population size; rate of unemployment; changes in the rate of unemployment; per capita agricultural production; per capita arable land; and the rate of inflation. These instruments have been suggested in the literature by some authors. For instance, Sachs and Warner (1995) argue that countries with higher population densities are more likely to be open and have more international contacts. Frankel and Romer (1999) find that once population is controlled for geographical variables, it represents only a small share of variations in trade.

Moreover, the literature on endogenous tariffs suggests that unemployment is an important determinant of tariffs (MAGEE et al. 1989). Trefler (1993) also notes that politicians insist that trade protection safeguards the livelihood of unemployed personnel in industries that are particularly threatened by international competition. In addition, due to the high tariff rates imposed on agricultural products in relation to other tradable, agricultural GDP per capita is also used as an instrument (MADSEN, 2001). Finally, the inflation rate serves as an important instrument of potential openness due to the inverse relationship between tariffs and inflation, given that customs tariffs are normally taken at face value (MAGEE et al., 1989). The result of the endogeneity test is presented in the appendix section.

4. ESTIMATION RESULTS

First, we consider the estimates in Table 6, where the coefficients are projected for the entire period. The tests for instruments overidentification do not reject the null hypothesis that the instruments are exogenous at 10% significance level. *Openness* (O) is measured by import plus export to GDP, the estimated coefficients of this variable in level are statistically insignificant, except for the estimates where the *Openness Variation* (ΔO) is considered. In general, these results suggest that openness has no permanent effects on productivity growth but may have direct temporary positive effects on growth.

In turn, when we analyze the interaction variable, $\Delta O^{*}\Delta ln\ Sd$, between *Openness Variation* (ΔO) and the growth rate of *Domestic Knowledge* ($\Delta lnSd$) a significant negative coefficient is observed. This result is an interesting finding because, although the openness itself does not seem to be clearly related to the growth of productivity, and even the openness change rate is positive and highly significant, it suggests that higher openness could weak internal knowledge efforts, at least in the short-run, in line with what is suggested by Rodriguez and Rodrick (2000). According to these authors, there is a conceptual distinction between quantity and quality effects of trade policies on growth. That is, openness influences higher volume of trade, but it does not necessarily improve productivity growth in the same sense or directions, because the volume of trade may also be influenced by other factors, like changes in world demand or geographical relations, which in turn affect growth.

Then, when we investigate openness as one possible channel which affects the internal knowledge progress, we find results that suggest a negative link among these variables. Moreover, this interaction variable is tested for categories of countries, keeping the negative relation in Middle and Low-income countries, but only being significant in emerging countries. In High-income countries, however, the relationship is positive but not significant.

The estimated coefficients of *Foreign Spillovers* ($\Delta lnSf$) are consistently positive and highly significant. Because $\Delta lnSf$ is based on the interaction between import penetration and foreign stock of knowledge, this result suggests that openness has temporary growth effects, provided that the country trades with countries that have positive knowledge stocks.

Table 6 Estimated Results of Equations (15) and (16) in IV, GMM, and Interaction by Categories of Countries

(1969-2014, 57 countries)

Variable	IV				GMM			
	1	2	3	4	5	6	7	8
Openness (O)	0.033	0.036			0.034	0.037		
ΔO			0.203***	0.203***			0.204***	0.204***
Δln Domestic Knowledge Stock (Sd)	0.003	0.003	0.001	0.000	0.003	0.003	0.001	0.000
Δln Foreign Knowledge Stock (Sf)	0.089***	0.089***	0.066***	0.066***	0.088***	0.089***	0.065***	0.065***
O*Δln Sd	-0.004				-0.004			
O*Δln Sd (High income)		0.018				0.018		
O*Δln Sd (Emerging income)		-0.007**				-0.007***		
O*Δln Sd (Middle income)		0.000				0.000		
O*Δln Sd (Low income)		-0.007				-0.007		
ΔO*Δln Sd			-0.099**				-0.099**	
ΔO*Δln Sd (High income)				0.228				0.226
ΔO*Δln Sd (Emerging income)				-0.102***				-0.102***
ΔO*Δln Sd (Middle income)				-0.021				-0.020
ΔO*Δln Sd (Low income)				-0.098				-0.097
Human Capital (hc)	-0.045**	-0.045**	-0.053**	-0.053**	-0.045**	-0.044**	-0.052**	-0.052**
hc2	0.007*	0.007*	0.010**	0.010**	0.007*	0.007*	0.010**	0.010**
ln population (pop)	0.064***	0.065***	0.056***	0.055***	0.064***	0.065***	0.055***	0.055***
population density (pop_den)	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
unemployment rate (unemp_rate)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Δunemp_rate	-0.001**	-0.001**	-0.002***	-0.002***	-0.001**	-0.001**	-0.002***	-0.002***
inflation (π)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Time Dummy (TD)	yes	yes	yes	yes	yes	yes	yes	yes
N	1046	1046	1046	1046	1046	1046	1046	1046
r2	0.222	0.223	0.105	0.106	0.352	0.353	0.255	0.255
Hansen J statistic Prob > chi2	0.83	0.83	0.83	0.83	0.80	0.78	0.84	0.83
Underidentification test Prob > chi2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Own elaboration

Legend: * p<.1; ** p<.05; *** p<.01

Notes: The Hansen J statistic is the overidentification test for all instruments. The following instruments are used for openness: hhe human capital index, the population in logarithmic form, population density, rate of unemployment, changes in the rate of unemployment, inflation, and all years' time dummies. As excluded instruments we use the first difference of openness and the agricultural GDP growth. For these results, we take out China; however, similar results are obtained if China is included into the models.

About the control variables, we find that the *Human Capital* is slightly significant and has a negative link with the growth rate of productivity, but when we take the square of this variable, it appears to be positivity related and significant. This implies that *Human Capital* (*hc*) performs better as a quadratic form, that is, the more investment and development in human capital, the more productivity grows at a proportionally higher rate. Also, a set of instrumental variables to openness are involved as indicated by the last section. Although most of these variables are not significant, it is important to include them in order to solve endogeneity issues.

Table 7 shows the results for the same regression, for the first half of the period, from 1969 to 1991. We chose this period because, after it, the global geopolitical order changed due to the the fall of the Union of Soviet Socialist Republics (USSR), which could have affected the international trade flow. *Openness* in this case is significant and positive in relation to the productivity growth for both *IV* and *GMM* regressions, whereas its *variation* is mostly positive and significant. These results suggest that openness was important for productivity growth in this period, but that the beneficial effects of openness come from knowledge, as is demonstrated by the growth rate of the *Foreign Spillovers* coefficient, which is positive and strongly significant.

Also, when we observe the interaction between both variables for *Openness* and the *Domestic Knowledge Stock*, it is positive although not significant, but, if we explore within countries by income categories, we find that for it is positive and strongly significant for low-income countries. This suggests that openness had positive temporary and permanent effects, along these two decades, on the internal efforts of this type of countries.

Finally, consider the results for the last 22 years of the sample in Table 8. The level of *Openness* does not have significance, but its *variation rate* is strongly significant and positive in relation to productivity growth. However, specifically when we analyze the interaction in differences regarding knowledge internal efforts, $\Delta O * \Delta Sd$, it has a negative and significant relation.

In the estimation, by categories of countries, one can see a positive but not significant relation for the *High-income* countries, while the relation is highly significant but negative for the

Emerging-income countries. This result suggests that, while openness may have been beneficial for developed countries in terms of their knowledge productivity, high degrees of openness do not seem to be suitable for developing emerging economies. However, for the rest of the countries categories, *Middle* and *Low-income*, the coefficients are also negative but do not present significance for the openness-knowledge link.

In general, this may suggest that, although trade relations among countries have intensified in the last two decades in contrast to the estimation of previous years, the result of all this has been positive for developed countries as opposed to developing countries, that is, openness has had temporary negative effects for the latter along the last two decades.

For these results, we can analyze that the *variation rate* of the openness itself has a direct relationship with productivity growth, but when we test this specifically in relation to internal knowledge efforts, the trade becomes a negative factor for countries' internal development of knowledge and technology, even more so for developing economies. That may suggest that a lower openness degree would be good for such economies.

Thus, according to these first results, the hypothesis that trade leads to knowledge spillovers between countries in terms of internal development efforts is only confirmed for the High-income category along nearly the last three decades. In contrast, for the rest of the countries evaluated in the present study, this hypothesis is not confirmed, because openness is either negative or not significant.

Table 7 Estimated Results of Equations (15) and (16) in IV, GMM, and Interaction by Categories of Countries

(1969-1991, 57 countries)

Variable	IV				GMM			
	1	2	3	4	5	6	7	8
Openness (O)	0.064**	0.044			0.064**	0.044		
ΔO			0.093*	0.100**			0.092*	0.100**
Δln Domestic Knowledge Stock (Sd)	-0.004	-0.006	-0.001	-0.002	-0.004	-0.006	-0.001	-0.001
Δln Foreign Knowledge Stock (Sf)	0.075***	0.075***	0.071***	0.073***	0.075***	0.075***	0.071***	0.073***
O*Δln Sd	0.004				0.004			
O*Δln Sd (High income)		-0.071				-0.07		
O*Δln Sd (Emerging income)		-0.006				-0.006		
O*Δln Sd (Middle income)		0.006				0.006		
O*Δln Sd (Low income)		0.425***				0.424***		
ΔO*Δln Sd			0.197				0.201	
ΔO*Δln Sd (High income)				-2.031				-1.856
ΔO*Δln Sd (Emerging income)				0.012				0.017
ΔO*Δln Sd (M income)				0.224				0.225
ΔO*Δln Sd (Low income)				2.082**				2.079**
Human Capital (hc)	-0.12	-0.160*	-0.048	-0.049	-0.12	-0.159*	-0.047	-0.047
hc2	0.021	0.032	0.009	0.01	0.021	0.031	0.009	0.01
ln population (pop)	0.074	0.128**	0.003	0.004	0.074	0.129**	0.004	0.006
population density (pop_den)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
unemployed rate (unemp_rate)	0.001	0.002*	0.001	0.001	0.001	0.002*	0.001	0.001
Δunemp_rate	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
inflation (π)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Time Dummy (TD)	yes	yes	yes	yes	yes	yes	yes	yes
N	295	295	295	295	295	295	295	295
r2	0.27	0.34	0.27	0.28	0.39	0.45	0.40	0.40
Hansen J statistic Prob > chi2	0.96	0.90	0.84	0.75	0.97	0.90	0.84	0.75
Underidentification test	0.04	0.04	0.05	0.05	0.04	0.04	0.05	0.05

Source: Own elaboration
Legend: * p<.1; ** p<.05; *** p<.01
See notes to Table 6.

Table 8 Estimated Results of Equations (15) and (16) in IV, GMM, and Interaction by Categories of Countries

(1991-2014, 57 countries)

Variable	IV				GMM			
	1	2	3	4	5	6	7	8
Openness (O)	0.028	0.026			0.028	0.027		
ΔO			0.137*	0.137*			0.139*	0.139*
Δln Domestic Knowledge Stock (Sd)	0.005	0.004	0.001	0.001	0.005	0.004	0.001	0.001
Δln Foreign Knowledge Stock (Sf)	0.096***	0.097***	0.076***	0.076***	0.096***	0.096***	0.074***	0.074***
O*Δln Sd	-0.007***				-0.007***			
O*Δln Sd (High income)		0.014				0.014		
O*Δln Sd (Emerging income)		-0.009**				-0.009**		
O*Δln Sd (Middle income)		0.003				0.003		
O*Δln Sd (Low income)		-0.011				-0.011		
ΔO*Δln Sd			-0.081**				-0.081**	
ΔO*Δln Sd (High income)				0.237				0.237
ΔO*Δln Sd (Emerging income)				-0.081***				-0.080***
ΔO*Δln Sd (M income)				-0.077				-0.075
ΔO*Δln Sd (Low income)				-0.117				-0.112
Human Capital (hc)	-0.045**	-0.045**	-0.042*	-0.042*	-0.044**	-0.045**	-0.041*	-0.041*
hc2	0.008*	0.008*	0.007*	0.007*	0.008*	0.008*	0.007*	0.007*
ln population (pop)	0.084**	0.082**	0.064***	0.064***	0.085**	0.083**	0.064***	0.064***
population density (pop_den)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
unemployed rate (unemp_rate)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Δunemp_rate	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
inflation (π)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Time Dummy (TD)	yes	yes	yes	yes	yes	yes	yes	yes
N	722	722	722	722	722	722	722	722
r2	0.21	0.21	0.15	0.15	0.34	0.35	0.29	0.29
Hansen J statistic Prob > chi2	0.88	0.86	0.78	0.77	0.88	0.86	0.77	0.77
Underidentification test	0.06	0.06	0.06	0.04	0.06	0.06	0.06	0.04

Source: Own elaboration
Legend: * p<.1; ** p<.05; *** p<.01
See notes to Table 6.

5. SENSITIVITY ANALYSES

To test the sensitivity of the results, model specification in Equation (15) and (16), is extended to allow for the interaction between openness and foreign knowledge spillovers. The following two equations are estimated:

$$\Delta ln\ tfp_{it} = \beta_0 + \beta_1^d\left(\Delta ln\ S_{it}^d\right) + \beta_2^f\left(\Delta ln\ S_{it}^f\right) + \beta_3^o(O_{it}) + \beta_4^{od}(O_{it})\left(\Delta ln\ s_{it}^d\right) + \beta_5^{of}(O_{it})\left(\Delta ln\ s_{it}^f\right) + \beta_6^{hc}(hc) + \beta_7^{hc^2}(hc^2) + \beta_8^I(I_{it}) + \varepsilon_{it}, \qquad (17)$$

$$\Delta ln\ tfp_{it} = \beta_0 + \beta_1^d\left(\Delta ln\ S_{it}^d\right) + \beta_2^f\left(\Delta ln\ S_{it}^f\right) + \beta_3^o(\Delta O_{it}) + \beta_4^{od}(\Delta O_{it})\left(\Delta ln\ s_{it}^d\right) + \beta_5^{of}(\Delta O_{it})\left(\Delta ln\ s_{it}^f\right) + \beta_6^{hc}(hc) + \beta_7^{hc^2}(hc^2) + \beta_8^I(I_{it}) + \varepsilon_{it}, \qquad (18)$$

Following the seminal work of Coe and Helpman (1995) and the strategy used by Madsen (2009), as well as the related empirical literature, we include such interaction term. Coe and Helpman (1995) multiplied *O* and Δ*lnSf* to capture the role of international trade. They reasoned that, although *Sf* constructs by the import-weighted stock of knowledge, these weights are fractions that add up to one and, therefore, do not implies necessarily openness. In this study we use the weighting scheme of Lichtenberg and de la Potterie (1998) to construct *Sf*, whose weights do not add up to one, but are influenced by imports, which is twice counting. Madsen (2009) states that the importance of making the interaction between *O* and *lnSf* is to investigate whether knowledge spillovers through the openness channel influence growth in a non-linear way.

The results for this analysis, presented in Table 9, show that the estimated coefficients of Δ*O**Δ*lnSf* are not significant, which suggests that, for most of the countries in the sample, a higher openness index does not influence the country's capacity to absorb knowledge. That suggests more about institutional factors, for instance. However, the estimated coefficients of Δ*lnSf* keep positive and strongly significative, which suggests that, for these countries, the quality of their imports is more important than the openness degree of the economy. In other words, knowledge spillovers are more efficient in improving productivity when imports come from countries closer to the technological frontier.

Also, a second sensitivity test is presented, as suggested by Coe and Helpman (1995). Below, we allow the initial model of the equations (15) and (16) to be extended by turning it into a production function, with *Y*, *K*, and *L*, been GDP, gross capital formation and labor respectively:

$$ln\, Y_{it} = \beta_0 + \beta_1^K(ln\, K) + \beta_2^L(ln\, L) + \beta_3^d\left(\Delta ln\, S_{it}^d\right) + \beta_4^f\left(\Delta ln\, S_{it}^f\right) + \beta_5^o(O_{it}) + \beta_6^{od}(O_{it})\left(\Delta ln\, s_{it}^d\right) + \beta_7^{hc}(hc) + \beta_8^{hc^2}(hc^2) + \beta_9^I(I_{it}) + \varepsilon_{it}, \quad (19)$$

$$ln\, Y_{it} = \beta_0 + \beta_1^K(ln\, K) + \beta_2^L(ln\, L) + \beta_3^d\left(\Delta ln\, S_{it}^d\right) + \beta_4^f\left(\Delta ln\, S_{it}^f\right) + \beta_5^o(\Delta O_{it}) + \beta_6^{od}(\Delta O_{it})\left(\Delta ln\, s_{it}^d\right) + \beta_7^{hc}(hc) + \beta_8^{hc^2}(hc^2) + \beta_9^I(I_{it}) + \varepsilon_{it}, \quad (20)$$

Table 10 shows the estimated results of this test. Both capital and labor coefficients are significant, with the elasticity of the labor being larger than the elasticity of the physical capital. That could suggest that most of the countries in the sample have more share of the labor factor than capital. That is, it is probable that the developing countries involve more labor-intensive processes while developed countries are more capital-intensive. For the rest of the essential variables in the present study, although they lose significance, the main results of the coefficient signs are not modified. The variable ΔO appear to be not-significant for the output but keep its positive sign. Moreover, the principal finding of this test is observed by the elasticity of the interaction between Openness (O and ΔO) and Domestic Stock of Knowledge ($\Delta lnSd$), which confirms its negative relation, such as one of our main results of the original model indicates, even when we observe the countries by category.

Table 9 Estimated Results of Equations (17) and (18) in IV, GMM, and Interaction by Categories of Countries

(1969-2014, 57 countries)

Variable	IV				GMM			
	1	2	3	4	5	6	7	8
ΔO*Δln Sf	0.066	0.076	-0.348	-0.385	0.063	0.073	-0.354	-0.393
Openness (O)	0.026	0.028			0.026	0.028		
ΔO			0.247*	0.251*			0.248*	0.252*
Δln Domestic Knowledge Stock (lnSd)	0.003	0.002	0.000	-0.002	0.003	0.002	0.000	-0.002
Δln Foreign Knowledge Stock (lnSf)	0.088***	0.089***	0.065***	0.065***	0.088***	0.088***	0.064***	0.064***
O*Δln Sd	-0.007***				-0.007***			
O*Δln Sd (High income)		0.019				0.019		
O*Δln Sd (Emerging income)		-0.007**				-0.007**		
O*Δln Sd (Middle income)		0.001				0.001		
O*Δln Sd (Low income)		-0.006				-0.006		
ΔO*Δln Sd			-0.089**				-0.089**	
ΔO*Δln Sd (High income)				0.296				0.294
ΔO*Δln Sd (Emerging income)				-0.096***				-0.096***
ΔO*Δln Sd (M income)				0.065				0.071
ΔO*Δln Sd (Low income)				-0.010				-0.005
Human Capital (hc)	-0.045**	-0.044**	-0.055***	-0.055***	-0.045**	-0.044**	-0.054***	-0.054***
hc2	0.007*	0.007*	0.010**	0.010**	0.007*	0.007*	0.010**	0.010**
ln population (pop)	0.060**	0.061**	0.057***	0.056***	0.060**	0.061**	0.056***	0.055***
population density (pop_den)	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
unemployed rate (unemp_rate)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Δunemp_rate	-0.001**	-0.001**	-0.002***	-0.002***	-0.001**	-0.001**	-0.002***	-0.002***
inflation (π)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Time Dummy (TD)	yes	yes	yes	yes	yes	yes	yes	yes
N	722	722	722	722	722	722	722	722
r2	0.22	0.22	0.10	0.10	0.35	0.36	0.22	0.21
Hansen J statistic Prob > chi2	0.87	0.87	0.76	0.74	0.87	0.87	0.76	0.74
Underidentification test	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Legend: * p<.1; ** p<.05; *** p<.01

Table 10 Estimated Results of Equations (19) and (20) in IV, GMM, and Interaction by Categories of Countries

(1969-2014, 57 countries)

Variable	IV				GMM			
	1	2	3	4	5	6	7	8
ln K	0.028**	0.028**	0.029**	0.028**	0.028**	0.028**	0.029**	0.028**
ln L	0.671***	0.667***	0.669***	0.669***	0.673***	0.669***	0.671***	0.671***
Openness (O)	-0.035	-0.031			-0.037	-0.033		
ΔO			0.115	0.100			0.110	0.095
Δln Domestic Knowledge Stock (lnSd)	0.040**	0.061*	0.026*	0.029*	0.040**	0.061*	0.026*	0.029*
Δln Foreign Knowledge Stock (lnSf)	0.080	0.082	0.058	0.058	0.085	0.087	0.063	0.064
O*Δln Sd	-0.015				-0.015			
O*Δln Sd (High income)		-0.179*				-0.180*		
O*Δln Sd (Emerging income)		-0.021				-0.021		
O*Δln Sd (Middle income)		-0.026				-0.026		
O*Δln Sd (Low income)		-0.074				-0.075		
ΔO*Δln Sd			-0.053				-0.052	
ΔO*Δln Sd (High income)				0.559				0.554
ΔO*Δln Sd (Emerging income)				-0.037				-0.036
ΔO*Δln Sd (M income)				-0.577				-0.572
ΔO*Δln Sd (Low income)				0.166				0.166
Human Capital (hc)	-0.029	-0.034	-0.092	-0.095	-0.025	-0.031	-0.089	-0.092
hc2	0.020	0.021	0.032	0.033	0.019	0.020	0.032	0.033
ln population (pop)	0.872***	0.876***	0.912***	0.920***	0.867***	0.871***	0.908***	0.916***
population density (pop_den)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
unemployed rate (unemp_rate)	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004
Δunemp_rate	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001	-0.002	-0.002
inflation (π)	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
Time Dummy (TD)	yes	yes	yes	yes	yes	yes	yes	yes
N	648	648	648	648	648	648	648	648
r2	0.62	0.63	0.62	0.62	0.93	0.93	0.93	0.93
Hansen J statistic Prob > chi2	0.81	0.81	0.76	0.74	0.81	0.81	0.76	0.74
Underidentification test	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00

Legend: * p<.1; ** p<.05; *** p<.01

6. CONCLUSIONS

This dissertation provides an empirical study of the relationship or influence that trade openness has on the growth of TFP in the sense that it is a channel of transmission of knowledge spillovers that affect the technological capacity within economies. Since the seminal article of Coe and Helpman (1995), a wide number of researches have proposed to investigate the determinants of productivity growth and its relationship with international trade, but they have done it mainly for the OECD countries. The focus of this work was to extend this discussion to a sample that also includes developing countries. This dissertation aimed not only to study openness as a channel of spillovers but also to investigate how it influences the domestic generation of knowledge and the productivity of the economies by categories of countries.

The results reveal that the degree of openness does not have a permanent effect on TFP growth, although in variation rate it shows a significant and positive impact on TFP, which implies that, in the short-run, a higher openness degree leads gains of TFP growth. This result is supported by all estimates. Another variable that presents a very important influence on TFP growth is the Foreign Stock of Knowledge that countries import from others with higher levels of technological development. For the countries that are more distant from the technological frontier, it is important, in the short term, to contact those countries that have technologically developed intermediate and finals goods because this implies savings in terms of time and resources when it is necessary to carry out any productive or industrial process. However, it does not necessarily imply that these technologies are developed internally by the economies, in a process termed here as internal efforts of the countries.

The main idea investigated in this study was the interaction between openness (in level and differences) and the Domestic Stock of Knowledge, finding a significant negative link for all the sample in most of the estimates. That suggests that when there is more openness, more competitiveness is generating as well, and, thus, those countries with weaker institutions or economies with less developed structures do not capture effectively the technology spillovers that are transmitted by international trade.

About such heterogeneity of countries, Coe, Hoffman, and Helpman (1998) find significant knowledge spillovers through the channel of imports from North to South. However, Madsen (2009) states that the interaction between the propensity to import, understood as openness, and its influence on the growth of research intensity in developing countries has not been tested so far. Madsen (2009) also argued that one of the main problems faced by developing economies is that they do not yet have the educational and research capacity to exploit effectively the technology that has been developed elsewhere.

Therefore, in order to present new evidence on this issue, both with theoretical and policy implications, we proposed to also test this hypothesis by categories of countries. We found that the level of openness, when interacted with domestic R&D efforts, has a positive but not significant impact on TFP in high and middle-income countries. For the rest of countries, the relationship is negative, being significant for emerging-income, both related to temporary and permanent effects. Hence, according to these results, these countries' performance is in line with Rodriguez and Rodrick's (2000) hypothesis, which is that countries with a large share of commodities in their GDP tend to specialize in this type of market to the detriment of their domestic technology industries.

Nevertheless, another interesting finding of our research is that the interaction between openness and domestic knowledge is positive and significant only for the low-income countries in the first two decades of the sample, from 1969 to 1991. We can note in the figures of descriptive statistics that after the 1990s trade relations among countries intensified through financial integration and trade agreements. That is a stylized fact; for example, the UE increased its influence area, the North American Free Trade Agreement (NAFTA) was created, and there was the more recent formation of the Trans-Pacific Partnership (TPP). The results suggest that the liberalization of trade after these two decades has been little beneficial for developing countries because, in the estimate for the second half of the period (1991-2014), the scene changes drastically, the coefficients turn negative and insignificant.

In general, we conclude that in, in the short run, openness is effectively a carrier of technological spillover that improves productivity growth but does not have a permanent effect in the long run, which corroborates the results of the literature. Nevertheless, when we test how the economies react internally in industrial and technological terms, openness has negative effects on productivity in developing countries, as exposed above. Finally, we performed the sensitivity analyses, finding slight or no changes in the main results for the research purposes. It is important to make a final comment. Although these results have been tested by different robustness tests, for future work is recommended contrasting such results using other measures of openness and stock of knowledge.

APPENDIX

Tests and Diagnostics

In this section, we proceed to do some tests on the prior estimations in order to identify several econometrics issues related to panel data methodology, following the guide proposed by Torres (2007). First, we prove if Random Effects (RE) is the appropriate model for this panel data through the Breusch-Pagan Lagrange multiplier (LM), which helps in the choice between a RE regression or a simple Ordinary Least Square (OLS) regression. The null hypothesis in the LM test is that variances across entities are zero. This is, there is no significant difference across units and, therefore, no panel effect.

In our case, table A1 shows the results for the LM test. For the *p-value* at a significance level of 95%, we reject the null hypothesis and conclude that RE is appropriate. I.e., there is evidence of significant differences across countries, so a simple OLS regression cannot be run.

Table A1. Breusch-Pagan Lagrange Multiplier Test for Random Effects

	Var	sd = sqrt(Var)
d_tfp	.0092519	.0961865
e	.0066519	.0815589
u	.0010521	.0324363
chibar2 (01)	828.33	
p-value	0.0000	

where d_tfp(country, time) = Xb + u(country) + e(country, time)

The second evaluation we propose to make is the Time-Fixed Effects test, in order to see if time fixed effects are needed when running a Fixed Effects (FE) model. It is a joint test to see if the dummies for all years are equal to zero; if they are, then no time fixed effects are needed.

Table A2 presents the FE model with the years as variables, followed by the Time-Fixed Effects test. The results show that the p-value is < 0.05, so we can reject the null hypothesis that the coefficients for all years are jointly equal to zero and, therefore, time-fixed effects are needed in this case.

Table A2. Time-fixed Effects Test

D.ln_tfp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln_sd						
D1.	.0001326	.0045016	0.03	0.977	-.0086948	.00896
ln_sf						
D1.	.0713149	.0051778	13.77	0.000	.0611617	.0814682
trade	-.0033659	.0028778	-1.17	0.242	-.009009	.0022772
dtrade	-.0109014	.015366	-0.71	0.478	-.041033	.0192302
o_sd	-.0014665	.005051	-0.29	0.772	-.0113712	.0084381
do_sd	.000154	.0407019	0.00	0.997	-.0796596	.0799676
year						
1971	-.0031507	.0061383	-0.51	0.608	-.0151875	.0088861
1972	-.0003785	.0061387	-0.06	0.951	-.012416	.0116591
1973	-.011204	.0061454	-1.82	0.068	-.0232546	.0008466
1974	-.0381823	.0062327	-6.13	0.000	-.0504042	-.0259604
1975	-.0344265	.0061593	-5.59	0.000	-.0465045	-.0223485
1976	-.0140889	.0061357	-2.30	0.022	-.0261204	-.0020573
1977	-.0223596	.0061456	-3.64	0.000	-.0344107	-.0103084
1978	-.0194791	.0061638	-3.16	0.002	-.0315659	-.0073923
1979	-.0227226	.0061424	-3.70	0.000	-.0347675	-.0106777
1980	-.0290579	.00616	-4.72	0.000	-.0411371	-.0169786
1981	-.0303401	.0061531	-4.93	0.000	-.0424059	-.0182743
1982	-.0370123	.0061877	-5.98	0.000	-.049146	-.0248787
1983	-.0330735	.0061477	-5.38	0.000	-.0451288	-.0210182
1984	-.0273721	.0061433	-4.46	0.000	-.0394186	-.0153256
1985	-.0326655	.0061339	-5.33	0.000	-.0446936	-.0206373
1986	-.0112271	.006196	-1.81	0.070	-.0233771	.0009229
1987	-.0136988	.0061429	-2.23	0.026	-.0257446	-.001653
1988	-.0234562	.0061487	-3.81	0.000	-.0355134	-.0113991
1989	-.0303749	.0061517	-4.94	0.000	-.0424379	-.0183119
1990	-.0209196	.0061474	-3.40	0.001	-.0329741	-.008865
1991	-.0255513	.0061492	-4.16	0.000	-.0376095	-.0134931
1992	-.0240417	.0061751	-3.89	0.000	-.0361506	-.0119327
1993	-.016394	.0061744	-2.66	0.008	-.0285014	-.0042865
1994	-.0178876	.0061635	-2.90	0.004	-.0299739	-.0058014
1995	-.0200502	.0061949	-3.24	0.001	-.0321979	-.0079024
1996	-.0207352	.0061844	-3.35	0.001	-.0328623	-.008608
1997	-.0252978	.0061956	-4.08	0.000	-.037447	-.0131486
1998	-.0376965	.006196	-6.08	0.000	-.0498464	-.0255465
1999	-.0218403	.0062082	-3.52	0.000	-.0340141	-.0096664
2000	-.0166676	.0062095	-2.68	0.007	-.028844	-.0044912
2001	-.0263013	.0062239	-4.23	0.000	-.0385059	-.0140966
2002	-.012852	.0062101	-2.07	0.039	-.0250296	-.0006743
2003	-.0139664	.0062124	-2.25	0.025	-.0261484	-.0017844
2004	-.0082924	.0062379	-1.33	0.184	-.0205244	.0039396
2005	-.0168221	.0062548	-2.69	0.007	-.0290872	-.0045569
2006	-.0136035	.0062713	-2.17	0.030	-.025901	-.001306
2007	-.0142996	.0062825	-2.28	0.023	-.0266191	-.0019801
2008	-.037718	.0063181	-5.97	0.000	-.0501074	-.0253286
2009	-.0354968	.0064229	-5.53	0.000	-.0480916	-.022902
2010	-.0115849	.0062663	-1.85	0.065	-.0238726	.0007027
2011	-.0255946	.0062844	-4.07	0.000	-.0379179	-.0132713
2012	-.0282105	.0062838	-4.49	0.000	-.0405325	-.0158885
2013	-.0220712	.0062884	-3.51	0.000	-.0344023	-.00974
2014	-.0244485	.0062833	-3.89	0.000	-.0367696	-.0121273
_cons	.0228252	.0045309	5.04	0.000	.0139405	.0317099
sigma_u	.00827878					
sigma_e	.03272597					
rho	.06014619	(fraction of variance due to u_i)				

F(44, 2458) = 4.90 Prob > F = 0.0000

The following test proves the presence of heteroskedasticity in the estimated model. The null hypothesis is homoskedasticity, or constant variance. It is expected that this hypothesis will not be confirmed, because there are likely to be differences of variance between countries. Table A3 shows the results for this test. The p-value is < 0.05, so we can reject the null hypothesis of constant variance and, therefore, the model has the presence of heteroskedasticity.

Table A3. Heteroskedasticity Test

dtfp	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
dsd	-.0006193	.002743	-0.23	0.821	-.006001	.0047624
dsf	.0550964	.0057441	9.59	0.000	.0438264	.0663664
do_sd	-.0228886	.0307539	-0.74	0.457	-.0832277	.0374505
trade	.011789	.0056387	2.09	0.037	.0007259	.0228522
dtrade	.0496176	.0159012	3.12	0.002	.0184195	.0808158
hc	-.0059929	.0143125	-0.42	0.675	-.0340739	.0220881
sqr_hc	-.0023812	.0026949	-0.88	0.377	-.0076686	.0029062
ln_pop	.0163464	.0074146	2.20	0.028	.0017989	.0308938
pop_den	-5.18e-06	4.07e-06	-1.27	0.204	-.0000132	2.81e-06
unemp_rate	.0002075	.0002412	0.86	0.390	-.0002657	.0006806
dunemp	-.0029374	.0005206	-5.64	0.000	-.0039588	-.0019161
infl	-9.21e-06	1.24e-06	-7.45	0.000	-.0000116	-6.78e-06
cons	-.0272194	.0196551	-1.38	0.166	-.0657827	.011344
sigma_u	.02751737					
sigma_e	.02463524					
rho	.55509512		(fraction of variance due to u_i)			
F test that all u_i=0: F(52, 1169) = 2.21				Prob > F = 0.0000		

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	
chi2 (53)	3029.35
p-value	0.0000

where H0: sigma(i)^2 = sigma^2 for all i

One possible solution for this issue is to use the robust option into the FE and RE models to obtain heteroskedasticity-robust standard errors, also known as Huber-White estimators. For this reason, Section 4 only presented estimates for the models in their robust version.

Table A4 shows the results from the first-stage instrumental variable regressions. Most of instruments used for trade in level are significant and the r2 is of high value, which suggests that such instruments are valid and suitable to include into the model. The r2 are lower in the regressions side in which ΔO are dependent variables, and most of the estimated coefficients are insignificant. These results suggest that the instruments used for ΔO are not of high quality and that they may potentially give misleading coefficient estimates of ΔO. However, since the GMM estimates in Table 5-8 are almost identical to the IV estimates, the potential bias introduced using bad instruments is unlikely to be significant. Thus, we conclude that the openness lagged 1 year and the agricultural GDP (gross domestic product) are valid instruments, supported also by the Sargan-Hansen tests.

Table A4. Instruments for Trade. Twostep

Variable	O	Δ*O*
ln_pop	0.478***	-0.003
pop_den	0.001***	-0.000**
unemp_rate	-0.001	0.001**
Δunemp	-0.004*	-0.001
π	-0.000*	0.000
Δagr	0.004	-0.001
_cons	2.405***	0.099*
N	1010	1010
R^2	0.81	0.19

legend: * p<.1; ** p<.05; *** p<.01

Notes. pop_den = population density, ln_ pop = population in ln, unemp_rate = the rate of unemployment, agr = agricultural production, π = inflation rate, Δ = year difference estimator. Time-dummies and fixed effects are included in the regressions but not shown.

In order to test de cointegration revised in section 3.4, we proceed to apply the Wooldridge (2003) test for autocorrelation and the Kao (1999) and Westerlund (2005) tests of cointegration on a panel dataset. In the case of the Wooldridge test, there is the null hypothesis of no first-order autocorrelation. For the case of Kao and Westerlund tests, there is the common null hypothesis of no cointegration. The alternative hypothesis of the Kao test is that variables are cointegrated in all panels, while the Westerlund test supposes that the variables are cointegrated in some of the panels. This implies more constraint in the Kao test because it assumes a stronger hypothesis in relation to the other test.

When the first difference of a nonstationary process is stationary, the process is said to be integrated of order one, denoted $I(1)$. When a linear combination of several $I(1)$ series is stationary, the series are said to be cointegrated (ENGLE & GRANGER 1987). We test for cointegration because cointegration implies that the $I(1)$ series are in a long-run equilibrium; they move together, although the group of them can wander arbitrarily. In our case, we are interested in observing the long-run relationship between the growth rate of productivity and the openness in level, which is a nonstationary series, since it contains a unit root as proved by the Levin-Lin-Chu test and the Breitung test in section 3.4. From the p-value results of Tables A5 and A6, we cannot reject the null of the Autocorrelation test (for $\alpha=5\%$), and we reject the null of the Cointegration test. Hence, we conclude that the series is cointegrated and the inclusion of the variable openness in level is valid.

Table A5. Wooldridge Test for First-order Autocorrelation

Model of Equation (1) without countries category	F(1, 51) = 3.786 Prob > F = 0.0572
Model of Equation (1) with countries category	F(1, 51) = 3.555 Prob > F = 0.0651

Table A6. Tests for cointegration

	Kao Test	Westerlund Test
Model of Equation (1)	Unadjusted modified Dickey-Fuller t -32.3908 P-value 0.0000 Unadjusted Dickey-Fuller t -23.2661 P-value 0.0000	Variance ratio -3.5899 P-value 0.0002

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