Channels and Determinants for International Technology Diffusion from Developed Countries to Developing Countries: An Empirical Analysis

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Abstract

This article aims to study channels and determinants for international technology diffusion from developed countries to developing countries by implementing a two-stage econometric estimation with panel data. First, we study domestic and foreign sources of productivity by using Total Factor Productivity as the explained variable: domestic and foreign Research and Development (R&D) expenditures, bilateral trade and Foreign Direct Investments (FDI) stocks. Then, we study the effects of potential determinants for the speed of technology diffusion: Gross Domestic Product (GDP) per capita, free trade index, number of researchers in R&D, number of Internet users, number of patent publications, and geographic distance. Our results show that domestic and foreign R&D, bilateral trade and FDI are prominent sources of productivity for developing countries. There are R&D, trade and FDI spillovers from developed countries. Domestic and foreign GDP per capita and number of researchers are significant positive determinant of the speed of technology diffusion. Free trade degrees and number of Internet users have also a positive impact while geographic distance significantly slows down technology diffusion.

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Keywords: Channels and Determinants for International Technology Diffusion, Developed Countries, Developing Countries, Econometric Estimation.

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1. Introduction

There is a growing interest in the analysis of international technology diffusion in economic literature. There is a development issue for developing countries because technology diffusion permits to improve industries that enhance economic development, especially capital intensive industries. Moreover, firms can use modern technologies, increase their workers' wage and improve working conditions. New products may also appear in these developing countries with technology diffusion. Generally, technology diffusion comes from developed countries' innovations. Then, developing countries acquires new products and new processes previously discovered by developed countries. Information diffusion involves technology diffusion and makes that the entire world can benefit from converging technology levels (Geroski, 2000; Keller, 2002). In this paper, we identify the channels and determinants for technology diffusion from developed countries to developing countries.

The issue of technology diffusion has been studied in economic literature. Note that Keller (2004) makes a wide survey of economic literature for this topic. A first factor of technology diffusion is Research and Development (R&D) investment owing to R&D spillovers, the sources of which we need to find. Generally, the speed of technology diffusion between two countries increases with the volume of trade between them, especially the trade of intermediate goods (Rivera-Batiz and Romer, 1991; Grossman and Helpman, 1991; Eaton and Kortum, 2002). Developing countries import intermediate goods from developed countries and need to use modern technology to produce finished goods. Usually, international trade involves information flows between countries because of business interactions. Coe and Helpman (1995) find close results empirically by showing that the R&D spillovers effect increases with the openness of international trade. Economic literature has also proven that the speed of technology diffusion between two countries increases with Foreign Direct Investments (FDI) stock because of FDI spillovers for the country receiving it (Griliches and Hausman, 1986; Keller, 2002; Griffith, Redding and Simpson, 2003). For example, Japanese R&D investments in Asian developing economies increased nine-fold from 1993 to 2007 (Source: UNCTAD). Developing countries like China, Korea or India benefited from such Japanese investments. Multinational Firms (MNF) use labor force from a foreign country where they are located. Spillovers between countries appear because of worker training by MNF (Aitken and Harrisson, 1999; Fosfuri, Motta and Rønde, 2001). This is the reason why the relationship between MNF and subsidiaries located in foreign countries clearly overrides FDI (Markusen, 2002). International trade and FDI represent two important factors of technology diffusion. Ethier and Markusen (1996) studies the choice between international trade and FDI for a firm that wishes to sell its product in a foreign country by using a theoretical dynamic framework with technological externalities. A firm from the domestic country discovers a new product and benefits from a temporary monopoly (equal to two periods in the model). The firms from the foreign country do not invest in research in order to discover new products. The firm has a choice between exporting from its domestic country and locating a part of its output in the foreign country. According to the authors, localization involves greater absorption of information for other firms in the foreign country that can produce the new product faster. Then, technology diffusion seems to be faster with localization than with exports. But it represents a cost for the domestic firm because the new product is no longer in a monopoly situation. The choice between exporting and locating depends on the transport cost of exports and the monopoly rent of localization.

Economic literature analyzes the impact of public policies (especially trade policies) on technology diffusion. The reference model without diffusion is the framework of Spencer and Brander (1983) that analyzes the positive effect of a R&D subsidy on domestic R&D investment and national welfare in an international duopoly. Cheng (1987) designs a close framework within a dynamic model. Considering international technology diffusion, he shows that the R&D subsidy that only satisfies domestic interest may benefit from the foreign firm. It may also enhance diffusion. Grossman and Helpman (1991) implement a theoretical macroeconomic model with technological spillovers and study the economic impact of trade openness for a small country. They show that trade policies that reduce (respectively promote) international trade, especially trade of intermediate goods, like tariffs or quotas (respectively subsidies) have a negative (respectively positive) effect on innovations and technology diffusion via knowledge spillovers. For example, a tariff cut involves an increase in trade volume, trade through variety of intermediate goods and stock of human capital through variety. Then, spillovers to foreign countries are greater. Reppelin-Hill (1999) makes an econometric study of the relationship between trade openness and speed of clean technology diffusion by using the example of the steel industry. He demonstrates that diffusion of clean technology is *"faster in countries that have more open trade policy regimes* [p. 284]*."* Geroski (2000) makes a survey of factors of technology diffusion. Information diffusion involves technology diffusion. He suggests that governments can subsidize technological externalities *"to promote … communication … and to motivate them* [p. 621]*."* Battisti (2008) also uses the example of environment and establishes that technology diffusion is a low process. Governments' policies may increase R&D investment but *"should also look at the adoption and the extent of use of innovations because that is the place where the generation of the benefits from inventions takes place* [p. 528]*."*

Economic literature also studies the impact of other variables that influence the speed of technology diffusion. The geographic distance between two countries has an impact on technology diffusion owing to its effect on the bilateral trade. Generally, previous studies proved that technology diffusion is faster inside a country than between two countries (Jaffe, Trajtenberg and Henderson, 1993; Eaton and Kortum, 1999; Branstetter, 2001). There is a border effect. Nevertheless, Irwin and Klenow (1994) do not find that the speeds of technology diffusion are not significantly different by taking the example of US firms as compared to foreign firms in semi-conductors industry from 1974 to 1992. Other papers study the significant negative effect of the distance in kilometers on the speed of technology diffusion (Keller, 2002; Bottazi and Peri, 2003).The impact of industrial protection is also studied through the role of patent publications. Patents may slow down technology diffusion because they involve a monopoly length on a new product or a new process. There is an optimal patent length (Nordhaus, 1969; Scherer, 1972; Tandon, 1982; Klemperer, 1990; Gilbert and Shapiro, 1990). Nevertheless, patent citations by other firms can be considered as a way to measure technology diffusion. Eaton and Kortum (1999) consider that patent publications in foreign countries are one possible measure of technology diffusion (even it is not a perfect indicator according to them) and show that the diffusion may depend on the ability to file a patent in the country and the patent cost.

Economic literature mentions three main channels for technology diffusion: R&D, trade and FDI. In this paper, we verify whether or not these variables are significant channels. We use a ratio of Total Factor Productivity (TFP) between developing countries and developed countries as the explained variable to find domestic and foreign sources of productivity. Then, we study the impact of potential sources of technology diffusion on domestic and foreign R&D, exports, imports and FDI stocks: GDP

per capita, free trade index, number of researchers in R&D, number of Internet users, patent publications, and geographic distance.

The results validate three sources of technology diffusion for developing countries: foreign R&D, bilateral trade and FDI stocks. It relates to R&D, trade and FDI spillovers. Developing countries' R&D expenditures enables to raise domestic TFP. Furthermore, such expenditures increase the levels of imports, exports and FDI stocks. Then, trade and FDI spillovers are stronger with developing countries' R&D expenditures. The results also illustrate a positive impact of domestic and foreign GDP per capita on the speed of technology diffusion. The ratio of GDP per capita has a positive effect too. Developing and developed countries' free trade index significantly accelerates technology diffusion by increasing the levels of trade, FDI and R&D expenditures. The number of each country's researchers in R&D has a positive impact on the speed of technology diffusion. The effect of number of developing countries' internet users is positive. Developed countries' patent publications seem to accelerate technology diffusion by increasing their R&D expenditures and the levels of bilateral trade and FDI. Finally, geographic distance slows down technology diffusion by reducing trade and FDI.

Section 2 introduces the model with each variable that influences technology diffusion and the expected sign of their impact. Section 3 presents the database that permits to implement the econometric study, with the sources of data. Section 4 shows the empirical impact of each channel on the ratio of TFP. Section 5 illustrates the impact of potential determinants of the speed of technology diffusion on each channel. Section 6 discusses the results. Section 7 concludes.

2. General Framework

This paper aims to study the sources of international technology diffusion from developed countries to developing countries. We implement a new framework with two stages.

First, we define a way to measure the speed of technology diffusion. We use Total Factor Productivity as the explained variable by referring to economic literature (Coe and Helpman, 1995; Eaton and Kortum, 1999; Keller, 2002). The indicator is a ratio of TFP between developing countries and developed countries:

$$TFP_{ijt} = \frac{TFP_{it}}{TFP_{jt}}$$

Index i denotes developing country, index j denotes developed country and index t denotes time. We use a relative level of TFP to benefit from an explained variable over three dimensions (i, j and t). Then, we can implement regressions by using explicative variables of both country i and country j. Furthermore, the ratio of TFP also relates to an indicator of technological catch up between developing countries and developed countries.

Economic literature mentions three main channels for technology diffusion that increase domestic level of TFP: foreign R&D, bilateral trade and FDI stocks.

- Domestic R&D expenditures influence domestic TFP in two ways. First, R&D may be cost-reducing. In this case, production costs decrease. Second, firms may create and produce new products with R&D expenditures by using the same volume of factors.

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- Foreign R&D expenditures may increase domestic TFP owing to R&D spillovers. Foreign innovations may benefit from firms from developing countries.
- Imports may be a significant source of TFP due because developing countries may import new products and new technologies. Economic literature mentions the role of intra industry trade and intermediate goods.
- Exports may also represent another channel for technology by increasing domestic TFP. Economic literature mentions the issue of "learning-by-exporting."
- Finally, FDI stocks from developed countries may also increase developing countries owing to FDI spillovers. Domestic firms benefit from located firms' knowledge.

Consider that the ratio of TFP is a function of these variables:

$$TFP_{ijt} = F(r_{it}, r_{jt}, X_{ijt}, M_{ijt}, FDI_{ijt})$$

where r_{it} (r_{jt}) denotes country i (j)'s R&D expenditures, X_{ijt} country i's exports to country j, M_{ijt} country i's imports from country j, FDI_{ijt} country i's inward FDI stock from country j. In the following sections, we will verify whether or not these variables are significant sources of productivity for developing countries.

Second, we try to identify potential sources of international technology diffusion that influence developing countries' TFP via the three channels. According to previous studies and economic intuitions, we assume that the following variables are potential sources.

- An income effect. Both countries' GDP influence the speed of technology diffusion. Income inequalities between the two countries may be a crucial source too.
- The free trade degree of each country (Grossman and Helpman, 1991; Reppelin-Hill, 1999; Geroski, 2000). Economic literature proves that trade policy instruments that increase (reduce) international trade between two countries accelerate (slow down) technology diffusion between them.
- The role of human capital (Eaton and Kortum, 1996; Xu, 2000). The role of developed countries' researchers in R&D is prominent because they discover new technologies. Developing countries also need researchers to use foreign technologies. Furthermore, researchers allow increasing R&D expenditures to increase domestic productivity.
- Industrial protection with patent publications on new products or new processes. Patents generally slow down technology diffusion. But it may also encourage innovation for patentee firms and increase spillovers. Then, the effect may be positive.
- Geographic distance may slow down technology diffusion between two countries. Economic literature has shown that distance generally reduce trade flows and FDI stocks (Bergstrand, 1985; Egger and Pfaffermayr, 2004).
- Modern telecommunications (Mansfield, 1985). The speed of technology diffusion may depend on the number of developing countries' Internet users. Technology diffusion occurs due to information diffusion. Developing countries need modern telecommunications to benefit from information diffusion.

Consider R&D expenditures, exports, imports and FDI stocks as explained variables:

$$r_{it} = F(y_{it}, FT_{it}, RES_{it}, INT_{it})$$

$$r_{jt} = F(y_{jt}, FT_{jt}, RES_{jt}, PAT_{jt})$$

$$X_{ijt} = F(y_{it}, y_{jt}, FT_{it}, FT_{jt}, RES_{it}, RES_{jt}, INT_{it}, PAT_{jt}, DIST_{ij})$$

$$M_{ijt} = F(y_{it}, y_{jt}, FT_{it}, FT_{jt}, RES_{it}, RES_{jt}, INT_{it}, PAT_{jt}, DIST_{ij})$$

$$FDI_{ijt} = F(y_{it}, y_{jt}, FT_{it}, FT_{jt}, RES_{it}, RES_{jt}, INT_{it}, PAT_{jt}, DIST_{ij})$$

where y_{it} (y_{it}) denotes country i (j)'s GDP per capita, FT_{it} (FT_{jt}) country i (j)'s free trade index, RES_{it} (RES_{jt}) country i (j)'s number of researchers in R&D, INT_{it} country i's number of Internet users, PAT_{jt} country j's number of patent publications, and $DIST_{ij}$ geographic distance between country i and country j. Table 1 illustrates the expected impact of each explicative variable.

Table 1 – Expected impact of each explicative variable on the speed of technology diffusion

y_{it}	y_{jt}	FT_{it}	FT_{jt}	RES_{it}	RES_{jt}	INT_{it}	PAT_{jt}	$DIST_{ij}$
+	+	+/−	+/−	+	+	+	+/−	−

Source: author.

Note that the expected impact of patent publications is ambiguous. It may slow down international technology diffusion by creating monopolies on new technologies. But as we said before, it may encourage further innovations that increase spillovers. The effect of each free trade index is also ambiguous. Free trade is supposed to increase the level of trade. But it may reduce R&D expenditures because theoretical studies proved that trade policy may increase R&D (Spencer and Brander, 1983; Reitzes, 1991).

3. Data

We use panel data with 20 developing countries (index i) and 10 developed countries (index j) over the period 1996-2010 (index t).[2] [3] Then, we have 200 couples of countries over 15 years. Table 2 illustrates the definition and the source of data.

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[2] Developing countries are: Bolivia, Brazil, Chili, Algeria, Egypt, Indonesia, India, Morocco, Mexico, Malaysia, Peru, Philippines, Paraguay, Russia, Thailand, Tunisia, Uruguay, Venezuela, and Cote d'Ivoire.
[3] Developed countries are: United States, Germany, Japan, France, United Kingdom, Canada, Australia, Belgium, Netherlands, and Austria.

Table 2 – Definition and source of each variable

Variable	Definition	Source
TFP_{ijt}	Ratio of TFP between country i and country j at time t	CEPII
r_{it}	Country i's R&D expenditures at time t in USD	World Bank WDI
r_{jt}	Country j's R&D expenditures at time t in USD	World Bank WDI
X_{ijt}	Value of country i's exports to country j at time t in millions of USD	Chelem, COMTRADE
M_{ijt}	Value of country i's imports from country j at time t in millions of USD	Chelem, COMTRADE
FDI_{ijt}	Value of FDI stock from country j to country i at time t in millions of USD	OECD, US BEA
y_{it}	Country i's GDP per capita at time t in USD	World Bank WDI
y_{jt}	Country j's GDP per capita at time t in USD	World Bank WDI
FT_{it}	Country i's index of free trade degree at time t	Heritage Foundation
FT_{jt}	Country j's index of free trade degree at time t	Heritage Foundation
RES_{it}	Number of country i's researchers in R&D at time t (per million people)	World Bank WDI
RES_{jt}	Number of country j's researchers in R&D at time t (per million people)	World Bank WDI
INT_{it}	Number of country i's Internet users at time t (per 100 people)	World Bank WDI
PAT_{jt}	Number of patent publications by firms from country j at time t	WIPO
$DIST_{ij}$	Geographic distance between country i's biggest city country j's biggest city in kilometers	CEPII

Source: author.

We implement two-stage econometric estimations. First, we analyze the channels for technology diffusion. Second, we study the impact of potential sources of technology diffusion via their impact on channels.

4. The Significant Channels for Technology Diffusion

As we said previously, there are domestic and foreign sources of productivity. We implement an econometric regression for the following equation:

$$\log TFP_{ijt} = \alpha_0 + \alpha_1 \log r_{it} + \alpha_2 \log r_{jt} + \alpha_3 \log X_{ijt} + \alpha_4 \log M_{ijt} + \alpha_5 \log FDI_{ijt} + \varepsilon_{ijt} \qquad (1)$$

The term ε_{ijt} is supposed to denote a white noise such as its mean is null and its standard-error equals to one. The coefficients α_2, α_3, α_4 and α_5 measure the speed of technology diffusion from developed countries to developing countries.

Note that there is a high risk of endogenous explicative variables. For example, we know that there are strong correlations between exports, imports and FDI stocks. Table 3 illustrates the matrix of partial correlations between explicative variables:

Table 3 – Partial correlations between explicative variables in Equation (1)

(Log)	r_{it}	r_{jt}	X_{ijt}	M_{ijt}	FDI_{ijt}
r_{it}	1				
r_{jt}	0.0550	1			
X_{ijt}	0.5175	0.4429	1		
M_{ijt}	0.6331	0.5029	0.8566	1	
FDI_{ijt}	0.5842	0.4663	0.7463	0.8422	1

Source: author.

There are strong correlations between FDI, exports and imports. The nature of trade between developing countries and developed countries explains the correlation between exports and imports. Intra-firm trade represents a big part owing to the location of Multinational Firms (MNF) in Southern countries to benefit from lower production costs. It also explains the strong correlation with FDI. These variables may also depend on each level of R&D expenditures due to economic intuition. Theoretical studies proved that R&D expenditures influence trade flows. For example, firms' exports increase with their R&D expenditures. Then, there is a high risk of endogenous explicative variables. We implement econometric regressions between these variables to solve such a problem. We make residual series by removing their effects and use these series in next regressions. See Appendix A.

Table 4 illustrates the results of the econometric regression. We have to integrate effects because of panel data. According to the Hausman test, we choose fixed effects by rejecting the assumption of random effects because the probability is lower than ten percent.

Table 4 – Results of the econometric regression for TFP

	$\log TFP_{ijt}$
$\log r_{it}$	0.0773***
	(0.0037)
$\log r_{jt}$	0.0176***
	(0.0066)
$\log X_{ijt}$	0.0086***
	(0.0019)
$\log M_{ijt}$	0.0703***
	(0.0046)
$\log FDI_{ijt}$	0.0164***
	(0.003)
Constant	-2.303***
	(0.1372)
R-squared	0.9826
Adjusted R-squared	0.9813
Observations	3,000
Effects	FE[a]
Hausman Statistic (Prob. that H_0 is true)[b]	17.48 (0.004)

Source: author.

Note: Robust standard-errors are between parentheses.[4] ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. [a] FE denotes fixed effects. [b] H_0 denotes the assumption of a model with random effects.

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[4] Standard-errors are robust by implementing Ordinary Least Squared regression with individual indicator variables (by specifying individual dimension that relates to introduce fixed effects) and the White correction.

The results validate three channels for technology diffusion: R&D, trade and FDI. Each variable has a significant and positive impact on TFP. The positive impact of developed countries' R&D expenditures denotes the intensity of R&D spillovers. Note also the positive effect of developing countries' R&D expenditures. Domestic R&D relates to innovations and represents another way to increase domestic TFP. The impact of FDI is significantly positive. Then, technology diffusion also occurs owing to FDI spillovers. Finally, the impact of bilateral trade on TFP is significant and positive. First, the impact of exports relates to the concept of learning-by-exporting. Second, the impact of imports relates to the fact that developing countries benefit from foreign goods and technologies. Then, imports involve technological progress. Note that the impact of bilateral trade is stronger than the impact of FDI. The reason is that the impact of bilateral trade absorbs in part the impact of FDI because FDI stocks strongly depend on imports and exports.

Developing countries' R&D expenditures have a significant positive impact on exports, imports and FDI. See Appendix A. Developing countries' exports clearly depend on their innovations. Imports and FDI stocks also increase with R&D expenditures. Then, trade and FDI spillovers are stronger with domestic R&D investments. Domestic R&D expenditures increase not only domestic TFP but also foreign sources of productivity. Governments from developing countries should increase public R&D expenditures to accelerate technology diffusion from developed countries. These public expenditures represent a source of technology diffusion.

5. Impacts of Potential Sources of Technology Diffusion on R&D, Trade and FDI

Now, let us study the impact of potential sources of technology diffusion that we mentioned in Section 2 by searching their impact on each channel (R&D, imports, exports and FDI). First, let us verify whether or not there is a risk of endogenous explicative variables. Table 5 illustrates the matrix of partial correlations between explicative variables.

Table 5 – Partial correlations between potential sources of technology diffusion

(Log)	y_{it}	y_{jt}	FT_{it}	FT_{jt}	RES_{it}	RES_{jt}	INT_{it}	PAT_{jt}	$DIST_{ij}$
y_{it}	1								
y_{jt}	0.3273	1							
FT_{it}	0.4806	0.2492	1						
FT_{jt}	0.2906	0.7061	0.244	1					
RES_{it}	0.392	0.1828	-0.039	0.1689	1				
RES_{jt}	0.1858	0.5229	0.1737	0.4666	0.1292	1			
INT_{it}	0.6098	0.5730	0.4566	0.5382	0.3439	0.4455	1		
PAT_{jt}	0.0533	0.3591	0.0499	0.1945	0.0369	0.4758	0.1286	1	
$DIST_{ij}$	0.0411	0.0028	0.2269	-0.009	-0.315	0.2248	0.1075	0.0459	1

Source: author.

These values show that developed countries' GDP per capita is strongly correlated with their free trade index and number of researchers. GDP per capita may be a function of free trade degree and human capital. We need to verify whether or not GDP per capita is an endogenous explicative variable. In developing countries, GDP per capita may also depend on the share of Internet users because telecommunications are sources of income. There is a strong correlation between the two variables. Note that the number of researchers may also depend on the share of Internet users, even if the correlation is lower, because researchers need modern telecommunications to discover new technologies. Consider also a significant correlation between number of Internet users and free trade

index because foreign Internet Providers increase their services with trade openness. According to economic intuitions, the number of developed countries' patent publications may depend on their number of researchers in R&D. Such a correlation seems obvious. Firms files patents when they innovate i.e. when they invest in R&D. Investing in R&D, they need to hire researchers. Then, we solve the problem of endogenous explicative variables by removing the endogenous part of these explicative variables. See Appendix B.

5.1. Impacts on R&D Expenditures

First, let us analyze the impact on R&D expenditures. Consider the following equations:

$$\log r_{it} = \beta_0 + \beta_1 \log y_{it} + \beta_2 \log FT_{it} + \beta_3 \log RES_{it} + \beta_4 \log INT_{it} + \theta_{it} \tag{2}$$

$$\log r_{jt} = \beta_0^* + \beta_1^* \log y_{jt} + \beta_2^* \log FT_{jt} + \beta_3^* \log RES_{jt} + \beta_4^* \log PAT_{jt} + \theta_{jt}^* \tag{3}$$

The terms θ_{it} and θ_{jt}^* denote white noises such as their means are null and their standard-error equal to one. Table 6 illustrates the results of econometric regressions. In both cases, we integrate fixed effects.

Table 6 – Results of the econometric estimations for Equations (2) and (3)

	$\log r_{it}$	$\log r_{jt}$
$\log y_{it}$	0.9557*** (0.0191)	
$\log y_{jt}$		0.9198*** (0.0142)
$\log FT_{it}$	1.0396*** (0.0221)	
$\log FT_{jt}$		4.3645*** (0.0471)
$\log RES_{it}$	0.4342*** (0.0164)	
$\log RES_{jt}$		1.6184*** (0.0206)
$\log INT_{it}$	0.2228*** (0.0039)	
$\log PAT_{jt}$		0.2041*** (0.0114)
Constant	10.5670*** (0.1867)	8.8458*** (0.1231)
R-squared	0.9784	0.9969
Adjusted R-squared	0.9768	0.9967
Observations	300	150
Effects	FE	FE
Hausman Statistic (Prob. that H_0 is true)	71.54 (0.0000)	605.84 (0.0000)

Source: author.

Note: Robust standard-errors are between parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

First, there is an income effect. Each R&D expenditures increase with the level of domestic GDP per capita. Then, innovations clearly depend on economic growth. Economic crisis may slow down international technology diffusion by reducing developed countries' R&D expenditures.

Each free trade index significantly increases domestic R&D expenditures. Such a result means that countries strongly innovate under free trade due to a growing competition. Then, R&D spillovers are stronger when Northern and Southern countries' levels of free trade increase.

Each number of researchers has a significant impact on each level of R&D. The number of researchers from developing (developed) countries significantly increases the level of developing (developed) countries' R&D expenditures. The role of developed countries' researchers is important by increasing the level of developed countries' R&D expenditures. Then, R&D spillovers strongly depend on such a number of researchers in rich countries. Researchers from developing countries involve innovations in their countries. They appear to be a way to increase domestic R&D and TFP.

Note the positive impact of the share of developing countries' Internet users on their R&D expenditures. Developing countries need modern telecommunications to implement R&D projects. Then, it involves stronger trade and FDI spillovers.

The number of developed countries' patent publications has a positive and significant impact in a same way. The reason is the advantage from patents for patentee firms. Patents may involve further R&D investments because of the monopoly on a new product or a new process for patentees. Then, R&D spillovers to Southern countries may be stronger.

5.2. Impacts on Exports, Imports and FDI Stocks

Now, let us study the impact on bilateral trade and FDI stocks. Consider the following equations:

$$\log X_{ijt} = \gamma_0 + \gamma_1 \log y_{it} + \gamma_2 \log y_{jt} + \gamma_3 \log FT_{it} + \gamma_4 \log FT_{jt} + \gamma_5 \log RES_{it} + \gamma_6 \log RES_{jt} + \gamma_7 \log INT_{it} + \gamma_8 \log PAT_{jt} + \gamma_9 \log DIST_{ij} + \mu_{ijt} \qquad (4)$$

$$\log M_{ijt} = \gamma_0^* + \gamma_1^* \log y_{it} + \gamma_2^* \log y_{jt} + \gamma_3^* \log FT_{it} + \gamma_4^* \log FT_{jt} + \gamma_5^* \log RES_{it} + \gamma_6^* \log RES_{jt} + \gamma_7^* \log INT_{it} + \gamma_8^* \log PAT_{jt} + \gamma_9^* \log DIST_{ij} + \mu_{ijt}^* \qquad (5)$$

$$\log FDI_{ijt} = \delta_0 + \delta_1 \log y_{it} + \delta_2 \log y_{jt} + \delta_3 \log FT_{it} + \delta_4 \log FT_{jt} + \delta_5 \log RES_{it} + \delta_6 \log RES_{jt} + \delta_7 \log INT_{it} + \delta_8 \log PAT_{jt} + \delta_9 \log DIST_{ij} + \tau_{ijt} \qquad (6)$$

Table 7 illustrates the results of econometric estimations. Regressions (A) relates to Equations (4), (5) and (6). In Regressions (B), the variable y_{ijt} denotes the ratio of GDP per capita between country i and country j, RES_{ijt} the ratio of number of researchers in R&D between country i and country j, and INT_{ijt} the ratio of number of Internet users between country i and country j. In Regressions (B), we study the effect of income, human capital and telecommunications inequalities.

Table 7 – Results of econometric estimations for Equations (4), (5) and (6)

	$\log X_{ijt}$		$\log M_{ijt}$		$\log FDI_{ijt}$	
	(A)	(B)	(A)	(B)	(A)	(B)
$\log y_{it}$	0.3223***		0.8646***		0.8916***	
	(0.0664)		(0.0286)		(0.0534)	
$\log y_{jt}$	0.8564***		0.1936***		0.2585**	
	(0.1566)		(0.0609)		(0.1260)	
$\log y_{ijt}$		0.2432***		0.7918***		0.7798***
		(0.0653)		(0.0303)		(0.0554)
$\log FT_{it}$	0.7886***	0.5762***	0.7005***	0.3991***	0.8101***	0.5826***
	(0.0844)	(0.0697)	(0.0432)	(0.0405)	(0.0812)	(0.0704)
$\log FT_{jt}$	0.9495	2.6950***	1.0119***	3.5108***	2.9964***	6.0229***
	(0.7810)	(0.7068)	(0.2672)	(0.2302)	(0.5052)	(0.3945)
$\log RES_{it}$	0.0030		0.0796***		-0.0247	
	(0.0419)		(0.0223)		(0.0421)	
$\log RES_{jt}$	0.5670***		0.3356***		1.3120***	
	(0.2147)		(0.1101)		(0.2167)	
$\log RES_{ijt}$		0.0567		0.0171		-0.0381
		(0.0397)		(0.0224)		(0.0423)
$\log INT_{it}$	0.1290***		0.0846***		0.1149***	
	(0.0152)		(0.0076)		(0.0140)	
$\log INT_{ijt}$		0.2097***		0.0938***		0.1801***
		(0.0190)		(0.0084)		(0.0173)
$\log PAT_{jt}$	0.3168***	0.6587***	0.1047**	0.3616***	0.1139	0.3121***
	(0.1065)	(0.0831)	(0.0527)	(0.0456)	(0.1074)	(0.0926)
$\log DIST_{ij}$	-1.7753***	-1.6774***	-0.5496***	-0.5158***	-1.3322***	-1.3151***
	(0.3833)	(0.4137)	(0.1331)	(0.1842)	(0.2952)	(0.3184)
Constant	15.5923***	12.2061**	-0.6443	-1.3498	-1.1166	-1.2394
	(5.0739)	(5.1404)	(1.5157)	(1.8855)	(3.3342)	(3.4205)
R-squared	0.9435	0.9403	0.9798	0.9748	0.9314	0.9219
Adjusted R-squared	0.9393	0.9359	0.9783	0.9729	0.9263	0.9162
Observations	3,000	3,000	3,000	3,000	3,000	3,000
Effects	FE	FE	FE	FE	FE	FE
Hausman Statistic (Prob.)	41.61 (0.00)	25.58 (0.00)	58.84 (0.00)	37.79 (0.00)	46.02 (0.00)	34.12 (0.00)

Source: author.

Note: Robust standard-errors are between parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

First, we find a positive and significant impact of developing and developed countries' GDP per capita. The ratio of GDP per capita between developed and developing countries significantly increases the levels of bilateral trade and FDI stocks. Income inequalities seem to reduce trade and FDI. Imports and FDI spillovers are stronger between economically nearby countries. International inequalities may slow down technology diffusion from Northern countries to Southern countries.

The effect of each free trade degree is positive. Exports, imports and FDI increases with the level of each country's free trade degree. The effect of developed countries' free trade index on exports is significant only with Regression (B). Note that the coefficient for developed countries' free trade index is generally stronger. We may explain such a result by referring to the nature of trade between developed and developing countries. Intra-firm trade represents a big part owing to the location of Multinational Firms (MNF) from rich countries in Southern countries to benefit from lower production costs. Then, the role of Northern countries' trade policies on bilateral trade is prominent.

It also explains the strong correlation between exports, imports and FDI. Then, if countries remained under free trade, technology diffusion would be faster.

The number of developing countries' researchers in R&D significantly increase imports. The effect on exports is positive but not significant. Human capital may be a source of imports for developing countries because researchers need scientific equipment from developed countries. The effects of developed countries' R&D researchers on imports and exports are significantly positive. The number of developed countries' researchers significantly increases the level of FDI stocks while the effect of developing countries' researchers is negative and not significant. Note that the ratio of number of researchers drops the level of FDI while the effects on imports and exports are positive even if the effects are not significant. Location primarily depends on origin country's human capital because firms from rich countries aim to locate other activities than research. Research activities remain in origin countries.

The share of developing countries' Internet users has positive and significant impacts on exports, imports and FDI. Developing countries need modern telecommunications to increase trade and FDI spillovers. The ratio of number of Internet users significantly increases exports, imports and FDI. Telecommunications inequalities between developing and developed countries clearly reduce the levels of trade and FDI.

The number of developed countries' patent publications has a positive impact on exports, imports and FDI. Patent publications seem to involve trade creations between developed countries and developing countries. The effect on FDI is also positive. Patentee firms from rich countries may increase their business activity with developing countries to benefit from their technological monopolies. Then, patent publications may accelerate technology diffusion by increasing exports, imports and FDI.

The effects of geographic distance on exports, imports and FDI are significant. Distance reduces both exports and imports because it represents a further transport cost. It may slow down technology diffusion by reducing the level of trade. FDI stocks from developed countries to developing countries drop with geographic distance between them. Such results relates to the results of economic literature. It means that FDI and trade are complements. Then, geographic distance reduces trade and FDI spillovers.

6. Discussion

Table 8 summarizes the impact of each explicative variable on the speed of technology diffusion through the four channels (R&D, exports, imports, FDI).

Table 8 – Impact of each explicative variable on the speed of technology diffusion

y_{it}	y_{jt}	y_{ijt}	FT_{it}	FT_{jt}	RES_{it}	RES_{jt}	RES_{ijt}	INT_{it}	INT_{ijt}	PAT_{jt}	$DIST_{ij}$
+	+	+	+	+	+	+	+/−	+	+	+	−

Source: author.

- There are income effects. The speed of technology diffusion increases with each level of GDP per capita because they increase the levels of trade, FDI stocks and R&D expenditures. First, the impact of developing countries' income is positive. It relates to the development process of these countries because they benefit from modern technologies with the *"drive to maturity"* when

their income increases (Rostow, 1959). Second, the impact of developed countries' income is also positive. The reason is that developed countries' innovations increase with their domestic income and that technology diffusion depends on such innovations. Third, the ratio of GDP per capita between developing and developed countries has a positive impact on the speed of technology diffusion. Then, a drop in income inequalities accelerates technology diffusion from developed countries to developing countries.

- The effect of free trade index is positive. There is a positive impact of trade and FDI. Trade and FDI spillovers are stronger when countries remain under free trade. It also increases developed and developing countries' R&D expenditures. Firms are encouraged to innovate under free trade due to a growing competition. R&D spillovers are stronger too. Northern countries should promote free trade to accelerate technology diffusion to Southern countries. Southern countries should also remain under free trade.

- An increase of the number of researchers in each group of countries accelerates technology diffusion. First, developed countries' researchers achieve technological innovations. Then, R&D spillovers are stronger when firms from developed countries hire R&D researchers. There is also a positive and significant on bilateral trade and FDI. Second, the number of Southern countries' researchers increases the speed of technology diffusion via trade spillovers by increasing the level of imports even if the effect on FDI is negative. Domestic R&D increases with the number of researchers. Then, trade spillovers are also stronger when the number of developing countries' researchers grows by increasing R&D expenditures. Furthermore, firms from developing countries need skilled labor like researchers to use modern technologies that come from foreign countries. Such a result means that human capital is an important source of technology diffusion. Developing countries should invest in superior education to increase the number of researchers and to accelerate technology diffusion from rich countries.

- The impact of the number of developing countries' Internet users on the speed of technology diffusion is positive and significant. It increases domestic R&D. The role of modern telecommunications is prominent to benefit from faster technology diffusion. Then, Southern countries should invest in such telecommunications. Note the positive impact of the ratio of number of Internet users between developing and developed countries on exports, imports and FDI. Telecommunications inequalities slow down technology diffusion by reducing trade and FDI spillovers. Such a result confirms the idea that developing countries should invest in modern telecommunications.

- The effect of Northern firms' patent publications is positive. We find a positive and significant impact developed countries' R&D expenditures. It means that patentee firms are encouraged to innovate owing to technological monopolies. Patent publications also significantly increase trade and FDI because patentee firms want to benefit from their technological monopoly abroad.

- Geographic distance has a negative impact on the speed of technology diffusion. Technology diffusion between two countries is faster when they are geographically nearby. Distance reduces bilateral trade by increasing transport costs. It also reduces FDI stocks due to the strong and positive correlation with bilateral trade.

These results show that trade policies, telecommunications and superior education may influence the speed of technology diffusion.

7. Concluding Remarks

In this paper, we aim to study channels for technology diffusion from developed countries to developing countries by implementing an econometric estimation with panel data (60 couples of country, 15 years). We implement a two-stage analysis. First, we study the impact of domestic and foreign source of productivity by using a ratio of TFP between developing and developed countries as the explained variable. We verify whether or not domestic and foreign R&D expenditures, bilateral trade and FDI stocks are main channels for technology diffusion. Second, we study the impact of potential determinants of the speed of technology diffusion by impacting the channels. We use explicative variables like GDP per capita, number of researchers in R&D, share of Internet users, patent publications, geographic distance, and free trade degrees.

The results show that domestic R&D, rich countries' R&D, bilateral trade with rich countries and FDI stocks from rich countries are prominent channels for technology diffusion for developing countries by increasing their TFP. There are R&D, trade and FDI spillovers from developed countries. Developing countries' R&D expenditures increase the level of trade and FDI. Then, such R&D expenditures have not only a direct positive impact on domestic, but also accelerate technology diffusion. Then, governments from developing countries should invest in public R&D.

Several potential determinants significantly increase the speed of technology diffusion: each GDP per capita, free trade degrees, number of researchers and developing countries' number of Internet users, and patent publications by firms from developed countries. Geographic distance between developing and developed countries significantly slows down technology diffusion. Furthermore, the ratios of GDP per capita and share of Internet users between developing and developed countries significantly accelerate technology diffusion. Income and telecommunications inequalities slow down it. But the effect of the ratio of number of researchers in R&D is ambiguous. It increases bilateral trade between developing and developed countries but reduces FDI from developed countries to developing countries. Nevertheless, the effects are not significant.

According to the impact of free trade degrees, governments from developed countries may accelerate diffusion by reducing the number and the restraints of trade policy instruments. Developing countries should also reduce the levels of their trade policy instruments. Free trade would be the best way to increase the level of trade between developed and developing countries. The role of the WTO is prominent to accelerate technology diffusion and asymmetries of technological endowment between Northern countries and Southern countries. The TRIPs agreements aim to reduce such the technological gap between the two groups of countries. The success of such an objective depends on the success of the current trade negotiations.

Similarly, considering the significant impact of the ratio of GDP per capita, international economic organizations have to implement a redistribution system that benefits from Southern countries to accelerate technology diffusion. Telecommunications inequalities also significantly slow down technology diffusion. Then, international organizations should help developing economies to provide modern telecommunications in their countries. Finally, the positive impact of the number of developing countries' researchers in R&D is interesting. Brain drain represents a real threat for developing countries. They should find some ways to avoid emigrations of domestic researchers to rich countries.

Appendix

A. Endogenous Explicative Variables in Equation (1)

	$\log X_{ijt}$	$\log M_{ijt}$	$\log FDI_{ijt}$
$\log X_{ijt}$		0.0730***	0.0828***
		(0.0193)	(0.0144)
$\log M_{ijt}$			0.7152***
			(0.0384)
$\log r_{it}$	0.1812***	0.3313***	0.3477***
	(0.0333)	(0.0190)	(0.0276)
$\log r_{jt}$	0.9726***	0.5480***	0.9797***
	(0.0668)	(0.0363)	(0.0487)
Constant	-21.2122***	-12.1998***	-14.0834***
	(1.1652)	(0.7464)	(1.0893)
R-squared	0.9407	0.9748	0.9360
Adjusted R-squared	0.9364	0.9730	0.9513
Observations	3,000	3,000	3,000
Effects	FE	FE	FE
Hausman Statistic (Prob.)	48.43 (0.0000)	291.28 (0.0000)	30.63 (0.0000)

Source: author.

Note: Robust standard-errors are between parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

B. Endogenous Explicative Variables in Equations (2), (3), (4), (5) and (6)

	$\log INT_{it}$	$\log RES_{it}$	$\log RES_{jt}$	$\log PAT_{jt}$	$\log y_{it}$	$\log y_{jt}$
$\log FT_{it}$	3.8547***	0.4276***			0.7346***	
	(0.1390)	(0.0235)			(0.0321)	
$\log FT_{jt}$			2.0279***			3.8087***
			(0.0548)			(0.0979)
$\log INT_{it}$		0.1180***			0.1146***	
		(0.0046)			(0.0036)	
$\log RES_{it}$					0.1280***	
					(0.0192)	
$\log RES_{jt}$				1.3671***		1.0753***
				(0.0529)		(0.0380)
Constant	-14.5206***	5.5156***	-0.7510***	11.5869***	5.8082***	-5.5327***
	(0.5771)	(0.1032)	(0.2405)	(0.0396)	(0.1829)	(0.4453)
R-squared	0.3958	0.9120	0.5269	0.9743	0.8783	0.7401
Adjusted R-squared	0.3527	0.9057	0.5268	0.9725	0.8695	0.7214
Observations	300	300	150	150	300	150
Effects	FE	FE	RE	FE	FE	FE
Hausman Statistic (Prob.)	40.73 (0.00)	60.34 (0.00)	0.16 (0.69)	23.13 (0.00)	212.6 (0.00)	387.9 (0.00)

Source: author.

Note: Robust standard-errors are between parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

	$\log INT_{ijt}$	$\log RES_{it}$	$\log y_{it}$
$\log FT_{it}$	1.0514***	-0.0078	0.1454***
	(0.0870)	(0.0244)	(0.0237)
$\log FT_{jt}$	11.2100***	1.6764***	0.9077***
	(0.4862)	(0.1605)	(0.1066)
$\log INT_{ijt}$		0.0370***	0.0361***
		(0.0068)	(0.0051)
$\log RES_{ijt}$			-0.0225
			(0.0165)
Constant	-55.8620***	-7.8556***	-5.2590***
	(1.9658)	(0.7851)	(0.5369)
R-squared	0.6856	0.9152	0.9099
Adjusted R-squared	0.6630	0.9091	0.9033
Observations	3,000	3,000	3,000
Effects	FE	FE	FE
Hausman Statistic (Prob.)	28.01 (0.00)	66.54 (0.00)	323.09 (0.00)

Source: author.

Note: Robust standard-errors are between parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

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