Technology Adoption, Financial development, and Sectoral Productivity Convergence[*]

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Abstract

Why do not poor countries adopt better technologies available to become rich? By focusing on the differences between the least advanced and the most advanced technologies in the technology adoption process, I introduce imperfect creditor protection and entrepreneurs' skills in a multisector Schumpeterian growth model in which countries can adopt existing technologies. I show that limited access to credit only reduces the probability of adopting the most advanced technologies. The theory predicts that a country's level of financial development increases the likelihood of successful adoption of only more advanced technologies. However, this effect is non-existent beyond a certain level of financial development and proximity to the frontier. The model also predicts that sectors in countries with high financial development will converge faster to their steady-state than sectors in countries with low financial development. Also, within a country, sectors that grow faster at the frontier will converge less quickly than those with a slower growth rate at the frontier technology. Finally, the model exhibits convergence of sectoral productivity conditional on the intensity of use of technologies where finance does not affect the long-run technology gap, but only the speed of convergence of countries.

KEYWORDS: Schumpeterian growth, Technology adoption, Financial development, Productivity growth, Sectoral distance, Technology frontier.

JEL classification: O33, O40, O41, G28

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1 Introduction

Understanding why some countries industrialize faster than others is one of the most important objectives of economics. A consensus view in the literature is that the variations in income per capita across countries are mostly accounted for by differences in total factor productivity [1]. Restuccia & Rogerson (2008) and Hsieh & Klenow (2009) emphasized that missallocation of ressources among firms that differs across countries contribute largely for differences in productivity. Midrigan & Xu (2014) and **?** have shown that the inefficiency of financial system plays an important role in the misallocation of financial resources in the economy. Jerzmanowski (2007) also argued that observed differences in productivity growth is driven by differences in the technology used in production to confirm the work of Aghion et al. (2005) who had proved that technology adoption is a key channel through which productivity growth is achieved. Indeed, all countries should adopt the best technologies that would allow them to industrialize and develop faster. However, this does not happen. When financial markets are inefficient, it may not be profitable for the lender to lend the optimal funds to implement certain types of technologies which are more demanding in financial resources.

I study, in this paper, the role of proximity to the frontier in term of productivity and the role of credit constraints in the adoption of technologies within and across countries. There is substantial evidence that the lack of financial development is clearly a serious problem for many developing countries. Banerjee & Duflo (2005) have showed that the rates at which entrepreneurs can borrow in poor countries are large and dispersed. They suggested the lack of funding for advanced technologies to be a potential explanation for the productivity gap between India and the United States. Greenwood et al. (2013) provided a quantitative estimates of the effect of finance on missallocation in developing countries. Their analysis illustrates that a country like Uganda could more than double its output if it could adopt the world's best practice in the financial sector. The perfection of the financial system can then bring an important advantage in the adoption of technologies. As Aghion et al. (2005) have shown that the level of financial development no longer affects the level of GDP from a given threshold level of financial development, I document in the data a positive correlation between the level of financial development and the level of adoption of different technologies for countries with a low level of financial development. And, beyond a given level of financial development specific to each technology, the correlation becomes non-existent. I also show a positive correlation between the level of technology adoption and the sectoral proximity to the technological frontier. Finally, I show that the correlation between finance and technology adoption is also stronger in sectors or countries that are furthest from the technological frontier. Indeed, the data shows that the most financially developed countries are closest to the technological frontier.

The goal of this paper is therefore to build a theoretical model that fits with these facts described above, and to analyze the theoretical implications of the model on sectoral convergence across countries with regard to these facts. I consider a schumpeterian growth model with financing frictions that builds from Aghion et al. (2005). The basic framework is extended in order to address differences in less and more advanced technologies productivity. I incorporate the specificity of each sector in the process of technology adoption. For, sectors with more advanced technologies require larger investments and some skills to successfull the adoption. For example, selling clothes on the street is much different than starting a motorcycle manufacturing company. The former requires a small investment that yields returns relatively quickly and with little risk. The latter requires more funding and there is huge risk associated with financing such project if the financial system is unefficient. Another important and novel feature of the model is that a

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[1] See Klenow & Rodrìguez-Clare (1997), Prescott (1998), Caselli (2005) and Jones (2016), for example.

country may be successful in technological adoption and not be able to catch-up with the frontier productivity. I consider that the level of productivity of a country after an adoption will depend not only on the productivity of the sector at the frontier but also on the intensity or the efficiency with which the new technology is used. Indeed, Comin & Mestieri (2018) has documented that the intensity of using adopted technologies diverges between countries. The model is also extended by incorporating the entrepreneurial skills in order to take into account that entrepreneurs with more knowledge or skills in the sectors in which they wish to innovate could do so more easily given that technology transfer is a skill-intensive process. As in Howitt & Mayer-Foulkes (2005), I made the assumption that a country's stock of "effective skills" that can be used in adoption of technolgies depends on its level of development in each sector, relative to the global technological frontier from which it draws new ideas. Nelson & Phelps (1966) called it "absorptive capacity" which was in their model only an implicit function of human capital and Griffith et al. (2004) gave the evidence that skills are an important determinant of a country's absorptive capacity. Considering this absorptive capacity makes it possible to capture the variable of proximity to the technological frontier in the model as well as its impact on the probability of successful technology adoption.

I show that the perfection of financial markets matters for the adoption of the most advanced or the most distant technologies. And beyond a threshold level, the financial depth does not affect the probability of successful adoption of technologies. For the less capital intensive or less productive sectors, the adoption of their thechnology is easier and is not affected by the presence of credit constraints. This can induce entrepreneurs in developing countries with low financial development to adopt only less advanced technologies given that the adoption probability decreases with the level of the technology to be adopted. The results also show that when two countries engage in the adoption of an industry-specific technology, the country with the higher domestic productivity (or higher proximity to the frontier) in that industry has a higher probability to successfull the adoption of the new technology. The effect of the sectoral proximity to the frontier on technology adoption is also non-existent beyond a threshold level of sectoral proximity. A theoretical implication of the model is that it presents sectoral convergence conditional on the intensity of using the new technologies adopted. Countries with same intensity of using new technologies will converge to the same long-run productivity gap. Even if the level of financial development does not affect the long-run technological gap, it does however positively affect the speed of convergence towards the steady state of the technology gap. Also, within a country, sectors which grow faster at the frontier converge less quickly towards their steady-state than the sectors which experience low growth rate at the frontier.

My paper is related to the broad literature analyzing the channels driving the differences in productivities across countries discussed earlier. Specifically, my paper relates to the literature seeking to find why poor countries do not adopt more productive technologies. One strand of the literature has related the role of distortions or barriers to technology adoption (e.g., Parente & Prescott (1999); Aghion et al. (2005); Hsieh & Klenow (2014); **?**; Bento & Restuccia (2017), Comin & Nanda (2019)). According to this point of view, policies that make it possible to eradicate missallocation and especially in the financial system contribute to the adoption of technologies. Another strand of the literature emphasizes the role of complementarity and coordination of firms' decisions which can lead to more technology adoption (Matsuyama (1995); Buera et al. (2021)). The three papers most closely related to mine are Aghion et al. (2005), **?** and Comin & Nanda (2019). While Aghion et al. (2005) used a schumpeterian growth model to argue that credit constraints is important in explaining the cross-country differences in aggregate productivity, their model can not explain why some countries may not successfull the adoption of advanced technolgies. Indeed, in their paper, the framework is such that all innovators in the same country adopt the same average technology of the frontier without taking into account the specificity of each sector. As they pointed out in the conclusion of their working paper, financial development should be especially favorable to innovation in R&D-intensive sectors, where technology transfer requires much external finance. This paper looks, at the sectoral level, the effect of finance on the adoption of the most and the least advanced technologies. **?** meanwhile performed a model in which the advanced and intermediate technologies cannot be implemented when monitoring is not efficient and/or when there is a significant cash-flow problem. They presented a quantitative illustration where financial frictions induce entrepreneurs in India and Mexico to adopt less-promising ventures than in the United States, despite lower input prices. This framework is different at several details from their paper and document how finance can affect technology adoption whether a country is close to the frontier or far from the frontier. My question is not only whether financial constraints make certain countries unable to adopt advanced technologies, but also how absorptive capacity accelerates technology transfer and interact with the level of financial development. Unlike **?**, this paper predicts that the effect of the financial system is not indefinite, that is to say that from a given threshold level, financial development is no longer a driver for the adoption of the most advanced technologies. Comin & Nanda (2019) only focused on the role of the financial development and conducted an empirical analysis on 16 major technologies, across 17 advanced economies, from 1870 to 2000. This present work, in addition to being theoretical and empirical, goes beyond the results of Comin & Nanda (2019) and includes not only developing countries but also the absorptive capacity of countries.

This paper contributes to understand not only the importance of a perfect financial system in the adoption of more advanced technologies but it also helps to understand the positive impact of the host country's initial level of productivity on the success of technology adoption. It produces evidence on technology adoption and proximity to the frontier. The theoretical model and its implications help also to understand the role of the finance in the sectoral productivity convergence and show that the variations in sectoral productivity across countries and sectors are also driven by the variations in the intensity of using new technologies and in the sectoral productivity growth rate at the frontier. The rest of the paper is organized as follows. After a brief presentation of evidence on technology adoption and financial development from a constructed dataset in Section 2, Section 3 spells out the model. Section 4 characterizes the qualitative implications of the model followed by the conclusion in section 5.

2 Empirical evidence on technology adoption, sectoral proximity to the frontier and financial development

I summarize the empirical facts on technology adoption, financial development, and sectoral proximity to the technological frontier into three stylized "observations" that drive my model.

2.1 Data

Since relevant data for technology adoption are not available, I combine many types of data[2]. First, I use measures of technology diffusion from the HCCTA[3] dataset introduced in Comin & Hobijn (2004). This dataset contains historical data on the adoption of several major technologies over the last 200 years across a large set of countries. I then construct panel data at the technology-country-year level, measuring the intensity with which each technology is used in each country over time. Table 1 lists the technologies used in the econometric regression. As shown in Table

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[2] See Table 4 in the Appendix A.2 for detailed and description and sources of data.

[3] Historical Cross-Country Technology Adoption

Table 1: Description of technologies used in the econometric analysis

	Technology	**Measure**	**Sector**	**Countries**
1	Harvesters	Number in operation	Agriculture	100
2	Tractors	Number in operation	Agriculture	128
3	Electric production	KwHr produced	Industry	117
4	Railroad	Km of track installed	Industry	78
5	Electric arc steel	Tons produced	Industry	71
6	Blast furnace steel	Tons produced	Industry	43
7	Aviation pkm	Million passenger kilometers	Services	65
8	Cable TV	Number of users	Services	85
9	Commercial vehicles	Number in operation	Services	69
10	Computers	Number in operation	Services	112
11	Internet users	Number of individuals using internet	Services	125
12	Mail	Million units handled	Services	24
13	Radio	Number in operation	Services	103
14	Telegram	Telegrams sent	Services	18
15	Telephone	Number connected	Services	75
16	Private vehicles	Thousands of privately owned vehicles	Services	92
17	Television	Number in operation	Services	114
	Total			**130**

All measures are scaled by population and expressed in logarithms.

1, the set of technologies covers the three economic sectors (agriculture, industry and service). The heterogeneous nature of the technologies explored is also reflected in their measures. Some technologies are measured by the number of units in operation (e.g., cars, computers, Radio) and some that capture the ability to produce something (electric arc steel, electricity, telegraphic services) are measured by the total production or by the number of users (e.g., cellphones).

I follow the usual practice of using a private credit, the value of credits granted by financial intermediairies to the private sector divided by GDP, as a measure of financial development. As productivity increases through investment and technological progress or changes in work organization, the level of the value added per worker is taken as a proxy for sectoral productivity level[4]. Following the litterature on technology adoption, I consider the United States of America to be the frontier in the three major economic sectors; and the sectoral proximity is calculated by dividing the country's average productivity by the US average sectoral productivity in the same sector.

Observation 1 : *Across countries, technology adoption is positively correlated with credit-to-GDP ratio only for low financial developed countries.*

Figure 1 plots the average log of the total electric production per capita and the number of tractors adopted per capita acros countries from 1960 to 2002 against the average level of total loans to the economy per GDP. It appears consistent with a positive correlation of financial development (loans/GDP) and the level of techology adoption which vanishes once financial development has reached approximately a certain level. Aghion et al. (2005) showed the same figure between average log of GDP per capita and average level of financial development. Figure 1 constructs

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[4] Also, in the theoretical model, the value added per worker is proportional to productivity, see equation (3.9)

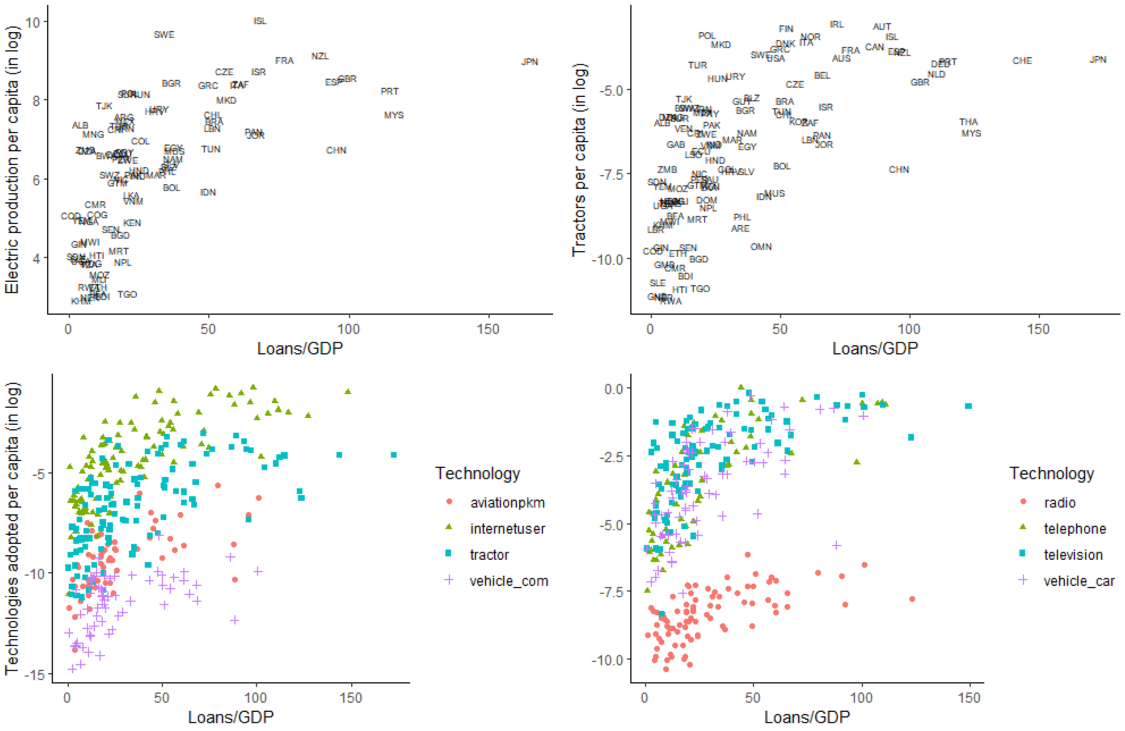

Figure 1: Average levels of financial development and log technology adoption per capita, 1960-2002

also scatter plots for other technologies. The relationship between the average level of technology adoption and the average level of financial development does not change significantly from one technology to another except for the threshold level from which the correlation becomes not significant. For example, the threshold level from which financial development is no longer correlated with technological adoption is between 50% and 60% of GDP for tractors and for electricity production, but between 40% and 45% of GDP for radio and commercial vehicles.

Observation 2 : *Sectoral proximity to the frontier is positively associated with more technology adoption.*

Figure 2 presents scatterplots showing the relationship of technology adoption level and the sectoral proximity to the United States[5]. The first row of the figure shows two examples of the relationship for average total tractors per capita adopted between 1991 and 2002 (resp. total electric production per capita) and the proximity to the United States in Agriculture (resp. proximity to the United States in Industry sector). It appears that the countries that adopt more technologies are at the same time those that are closest to the United States in terms of productivity. The relationships plotted in Figure 2 are consistent from one technology to another and are statistically significant at the 1% level. Table 5 presents the results of some regression analysis.[6]

The positive relationship illustrated in Figure 2 obviously says nothing about the direction of causality. While the usual interpretation is that technological adoption increases productivity, my

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[5] The sectoral proximity to the frontier is the agricultural (resp. industrial and service) productivitiy divided by the US productivity in the same sector.

[6] This analysis is intended for illustrative purposes only. A more in-depth analysis will be carried out later in section 2.2.

model not only explains that technological adoption moves closer to the frontier, but that some causality can also work in the opposite direction.

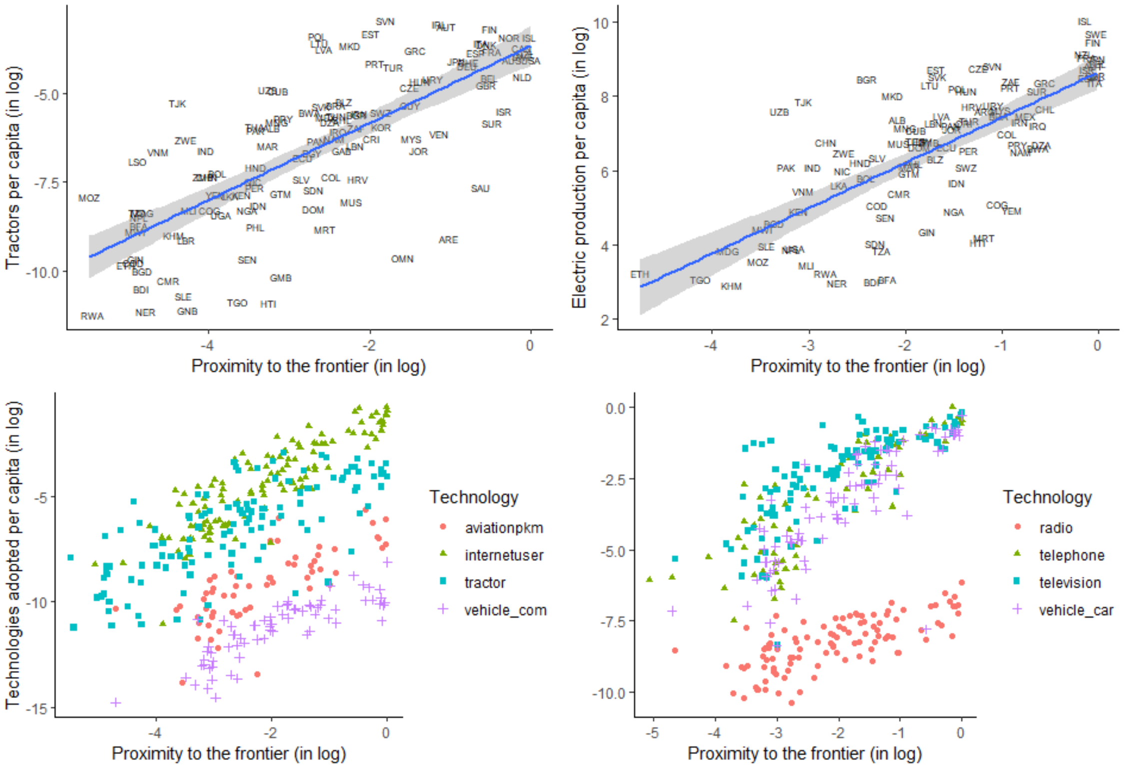

Figure 2: Average levels of sectoral proximity to the US and log technology adoption per capita, 1991-2002

Figures 1 and 2 only show the relation between average technology adoption level, financial development and the sectoral proximity to the frontier. They do not deal with the problem of possible endogeneity of sectoral distance and financial intermediation. Nor do they control for the effects of any other possible influences on technology adoption. Indeed, Figure 3 shows a positive relationship between financial intermediation and the proximity to the frontier. Countries that are close to the frontier are the same time those whore are more financial developed. Thus, the effect of one of these two variables on the adoption of technologies may not be real but simply pass through the other variable. For these, I turn to the following regression specification in the subsection 2.2.

2.2 Econometric Specification

I previously illustrated that finance is no longer correlated with technology adoption from a certain level of financial development. I also showed that sectoral proximity to the frontier is positively correlated with the level of technology adoption. However, the countries closest to the frontier are at the same time the most financially developed as illustrated in the Figure 3. I test these correlations in a linear regression model (2.1). I also make the finance variable interact with the sectoral proximity variable in the equation of technology adoption.

$$y_{cj} = \eta_j + \beta_1 FD_c + \beta_2 dist_{cj} + \beta_3 \left(FD_c * dist_{cj}\right) + \beta_4 \mathbf{X}_c + \varepsilon_{cj} \tag{2.1}$$

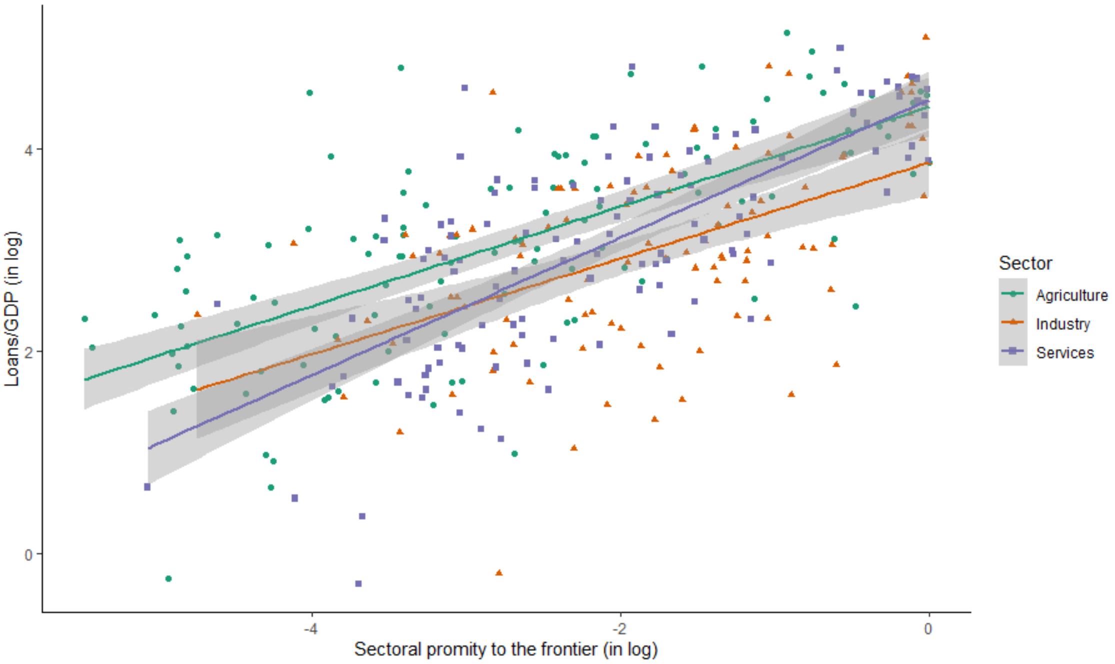

Figure 3: Average financial development and average sectoral proximity to the frontier in log, 1991-2003

y_{cj} denotes the average measure of the adoption of technology j in country c. All measures are scaled by population. I deal with the heterogeneity of measures in two ways. First, I take logarithms of the per capita technology measures as Comin & Nanda (2019). This removes the units of the analysis which go to the constant term. Second, I introduce a full set of technology fixed effects, denoted by η_j in the regression specification that captures the average diffusion path for each technology. Effectively these fixed effects imply that the dependent variable is the deviation of a country's adoption of a technology from the average adoption of that technology across countries. FD_c is the average measure of financial development (i.e., private credit to GDP ratio) across countries. $dist_{cj}$ is the proximity to the frontier of the country c in the sector of the technology j. Each technology is classified in one of the three economic sectors (agriculture, industry and services) as shown in the Table 1. The frontier is considered here to be the United States of America and $dist_{cj}$ is the logarithm of the average productivity A_j^c of the country c in the sector of the technology j divided by the US average sectoral productivity A_j^{us} in the same sector.

$$dist_{cj} = \log\left(A_j^c\right) - \log\left(A_j^{us}\right) < 0$$

The lower $dist_{cj}$ is, further the country is from USA in term of productivity. Hence β_1 (respectively β_2) measures the relationship between financial market depth (respectively sectoral proximity to the frontier) and country's relative rate of adoption of technologies. $\mathbf{X}_c$ is a vector of control variables such as income per capita, country's stock of human capital, institutions and their interaction with the financial development level. Indeed, many of the sources of omitted variable bias would stem from factors that have been shown to predict cross-country differences in development such as traditions or culture (Guiso et al. (2006)) and the quality of institutions (Manca (2010); Acemoglu et al. (2001)).

To analyze how the distance to the frontier affects the relationship that links financial development and technology adoption depending on the level of proximity to the technological frontier, the interaction variable between financial market depth and the distance to the frontier which is introduced into the model matters. The marginal effect of finance on the diffusion of technology is given by:

$$\frac{\partial y_{cj}}{\partial FD_c} = \beta_1 + \beta_3 * dist_{cj} \tag{2.2}$$

The equation (2.2) shows that the marginal effect of financial market depth on the adoption of technology depends on the sectoral distance of the country to the frontier. If $\beta_3 < 0$ then financial development makes it more easier for countries that are far from the frontier such as developing countries than those who are close to the frontier. Based on the correlation analysis, β_2 is expected to be positive and β_3 negative so that the marginal effect of financial development is higher for countries that are far from the frontier. The overall effect of finance on technology adoption parameter which is $\beta_1 + \beta_3 * dist_c$ is positive if only the sectoral proximity to the frontier for a country is then less than a critical value $dist_c^* = -\frac{\beta_1}{\beta_3}$.

Similarly, the overall effect of sectoral proximity to the frontier on technology adoption is given by the equation (2.3) below. If β_3 is negative then sectoral proximity affects more positively technology adoption in low financial development countries.

$$\frac{\partial y_{cj}}{\partial dist_{cj}} = \beta_2 + \beta_3 * FD_c \tag{2.3}$$

This effect is positive when the level of financial development is such that : $FD_c < -\frac{\beta_2}{\beta_3}$ and is significant if in addition :

$$N \left(\hat{\beta}_2 + \hat{\beta}_3 * FD_c \right)^2 \geq z_{\alpha/2}^2 \left[var(\hat{\beta}_2) + FD_c^2 * var(\hat{\beta}_3) + 2 * FD_c * cov(\hat{\beta}_2, \hat{\beta}_3) \right] \tag{2.4}$$

where $z_{\alpha/2} = F^{-1}\left(1 - \frac{\alpha}{2}\right)$ and F is the cumulative function of a standard normal distribution and N is the number of observations.

2.3 Regression Results

Table 2 presents the results for the estimation of the equation (2.1) and Table 5 reports the results from the baseline regression for six technologies separately. Note that technology fixed effects dummies are included in the estimations to absorb the technology heterogeneity.

Observation 3 : *The coefficient of association between financial development and technology adoption is higher for countries that are far from the technological frontier.*

As shown in Table 2, the level of financial development (first row) is insignificantly correlated with the level of technology diffusion. However, the coefficient of the proximity to the frontier (second row) is significant and positive showing that countries which have a low level of productivity and want to adopt very advanced technologies are less successful than the productive countries. More importantly, the association between distance and financial market development is larger for less productive countries (most distant from the frontier countries). This implies that finance plays a more important role on technology adoption in developing countries than in advanced countries since developed countries are characterized by a high level of financial development and developing countries by a low level of financial development. Using the results from the column (3)[7] in

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[7] Where I control for GDP per capita and human capital and interact only the sectoral proximity with the finance variable.

Table 2: Technology adoption, financial development and sectoral proximity to the frontier (1991-2003)

	log technology diffusion per capita					
	(1)	(2)	(3)	(4)	(5)	(6)
Loans/GDP	0.005***	0.000	-0.002	0.009	-0.007	-0.014
	(0.008)	(0.826)	(0.249)	(0.647)	(0.738)	(0.504)
Sectoral proximity (in log)	1.171***	0.261***	0.256***	0.242**	0.267**	0.275***
	(0.000)	(0.004)	(0.007)	(0.017)	(0.010)	(0.008)
Loans/GDP × Proximity	-0.005***	-0.005***	-0.005***	-0.004*	-0.005**	-0.005**
	(0.000)	(0.000)	(0.000)	(0.077)	(0.017)	(0.018)
GDP per capita (in log)		0.837***	0.630***		0.620***	0.516***
		(0.000)	(0.000)		(0.000)	(0.000)
GDP per capita × Finance				-0.001	0.000	0.004
				(0.659)	(0.814)	(0.105)
Human capital			0.668***		0.669***	0.937***
			(0.000)		(0.000)	(0.000)
Human capital× Finance						-0.009***
						(0.004)
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,159	1,159	1,105	1,159	1,105	1,105
R-squared	0.946	0.953	0.957	0.953	0.957	0.957

Robust p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 2, the threshold level of sectoral proximity to the frontier from which financial development no longer positively affects technology adoption is around 67. That is, countries whose sectoral productivity is lower than 67% of the US productivity can increase significantly their level of technology if they improve the level of their financial depth.

According to the data, both Mexico and Senegal had almost the same level of financial development in 2000 (around 14% of GDP). The estimates imply that increasing these two countries' financial development to the level of USA (49%) at the beginning of the century would have led to an increase in the adoption of technologies over the next years in Mexico's agrucultural sector by 50% and in Senegal by 78%; in Mexico's industry by 10% and in Senegal by 39%; in Mexico's service sectors by 17% and in Senegal by 53%. Since Senegal is less productive than Mexico in all sectors, it would benefit more from financial development than Mexico.

In columns 2–6 of Table 2, a set of control variables is used one after another to assess the robustness and significance of the coefficients. The coefficient of the sectoral distance changes very slightly but continues to remain statistically significant while the direct effect of finance becomes insignificant, suggesting that the control variables have addressed the relevant sources of omitted variable bias. However, the overall effect of financial development on technology adoption still remains positive and significant when considering the interaction with sectoral proximity. And this effect is higher for countries that are far from the technological frontier (lower $dist_c$). The control variables such as GDP per capita and human capital are positively correlated with the level of technologies adopted across countries.

Another argument that could be made in regard of robustness of the estimations is that a country lacking institutional qualities may not be able to adopt new technologies. Omitting organizational and institutional factors such as control of corruption, rule of law, political stability and absence of violence and terrorism can bias the estimates. In Table 3, I therefore include a measure of institutions variables[8], avaible from World Governance Indicators (2020) and find that the results are robust to the inclusion of these controls and their interaction with the measure of financial development. The estimations in Table 3 show that the quality of institutions are positvely correlated with the level of technogy adoption while their interaction with finance do not have predictive power over the technology adoption measures.

With regard to the results of the econometric regressions, some countries may succeed more quickly in adopting advanced technologies than others if they have a better financial system and higher productivity than other countries. It is not only differences in financial development that explain the differences in the level of technology adoption across developing countries, but also the level of productivity in the various economic sectors in which adoption takes place. The most productive countries are those that are more inclined to readily adopt advanced technologies. For example, India has had a higher level of financial development than Mexico since the 1980s, but Mexico does better in adopting almost all of the technologies listed in the HCCTA database. Indeed, Mexico is more productive in all the three economic sectors than India. However, finance plays a more important role in less productive sectors or countries.

Motivated by these observations, the next section constructs a model in which the level of proximity and financial level increases the adoption likelihood of the most advanced technologies.

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[8] Table 6 reports the results from regressions where I look at lagged financial development and lagged sectoral proximity. The results continue to remain robust using this specification.

Table 3: Robustess control with institutions variables: dependent variable: log technology diffusion per capita

	Traditions and institutions variables used					
	VA	**PV**	**GE**	**RQ**	**RL**	**CC**
Loans/GDP	-0.008	-0.006	-0.017	-0.014	-0.017	-0.015
	(0.712)	(0.772)	(0.405)	(0.503)	(0.433)	(0.447)
Sectoral proximity (in log)	0.255**	0.245**	0.227**	0.244**	0.228**	0.219**
	(0.013)	(0.017)	(0.029)	(0.020)	(0.029)	(0.037)
Loans/GDP×Proximity	-0.005**	-0.004**	-0.005**	-0.005**	-0.005**	-0.005**
	(0.014)	(0.049)	(0.018)	(0.028)	(0.018)	(0.019)
GDP per capita	0.511***	0.499***	0.447***	0.481***	0.493***	0.480***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP×Finance	0.002	0.002	0.005**	0.005*	0.005*	0.005**
	(0.398)	(0.401)	(0.035)	(0.053)	(0.090)	(0.048)
Human capital hc	0.706***	0.863***	0.797***	0.870***	0.829***	0.836***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
hc × Finance	-0.006*	-0.008**	-0.007**	-0.008**	-0.007**	-0.007**
	(0.072)	(0.014)	(0.028)	(0.011)	(0.021)	(0.021)
Institutions	0.291***	0.201***	0.390***	0.194*	0.244**	0.292***
	(0.003)	(0.008)	(0.000)	(0.071)	(0.014)	(0.001)
Loans/GDP×**Inst.**	-0.000	0.001	-0.004	-0.003	-0.003	-0.003
	(0.880)	(0.654)	(0.103)	(0.255)	(0.351)	(0.124)
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,094	1,094	1,094	1,094	1,094	1,094
R-squared	0.959	0.959	0.958	0.958	0.958	0.958

Robust pvalues in parentheses, Governance variables are **GE** :Government Effectiveness, **CC**: Control of Corruption, **VA** : Voice and Accountability, **PV**: Political Stability and Absence of Violence/Terrorism, **RQ** : Regulatory Quality, **RL** : Rule of Law

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

3 Theoretical model

The model economy follows Aghion et al. (2005) and economic activity occurs in countries which do not exchange goods or factors of production, but do use each others' technological ideas. Each country has a fixed population which is normalized to one, so that aggregate and per capita quantities coincide. Each individual lives two periods and is endowed with two units of labor in the first period and none in the second. At the end of the first period, households obtains a skill level and invest their savings in an innovation[9] project as entrepreneurs. The utility function is linear[10] in consumption , so that $U(c_1, c_2) = c_1 + \beta c_2$ where c_1 is consumption in the first period of life, c_2 is consumption in the second period of life, and $\beta \in (0, 1)$ is the rate at wich individuals discount the utility of consumption in period 2 relative to that in period 1.

3.1 Goods production sectors

Final good. There is a unique final good in the economy that is also used as an input to produce intermediate goods. I take this good as the numeraire. The final good is produced competitively using labor and a continuum of intermediate goods as inputs with the aggregate production function below:

$$Y_t = L_t^{1-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj \tag{3.1}$$

where $0 < \alpha < 1$, $A_{j,t}$ is the productivity in the sector j at time t, and $x_{j,t}$ is the input of the latest version of intermediate good j used in final-good production at time t. L_t is the number of production workers at time t. Since the final sector is competitive, the representative firm takes the prices of its output and inputs as given, then chooses the quantity of intermediate goods of each sector j to use in order to maximize its profit as follows:

$$\max_{\{L_t, [x_{j,t}]_{j\in[0,1]}\}} L_t^{1-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj - \int_0^1 p_{j,t} x_{j,t} dj - w_t L_t \tag{3.2}$$

where $p_{j,t}$ is the price of the intermediate good of variety $j \in [0, 1]$. The first order conditions for the firm in the final sector are given by:

$$\begin{cases} p_{j,t} = \alpha x_{j,t}^{\alpha-1} A_{j,t}^{1-\alpha} L_t^{1-\alpha} \quad \forall j \in [0,1] \\ w_t = (1-\alpha) L_t^{-\alpha} \displaystyle\int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj \end{cases}$$

The demand function for intermediate goods of variety j for the firm in the final sector is then given by :

$$x_{j,t} = \alpha^{\frac{1}{1-\alpha}} p_{j,t}^{-\frac{1}{1-\alpha}} A_{j,t} L_t \tag{3.3}$$

Intermediate goods production. In each intermediate sector, there is a monopoly whose production technology consists in using a unit of the final good to produce a unit of the intermediate good. Given that she is in a monopoly situation, she practices the highest price that the final sector producer would be ready to pay for the variety j under the hypothesis of a drastic innovation[11].

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[9] Technology adoption involves uncertain process of adapting ideas from the world technology frontier to the domestic economy. Innovation is necessary to transfer a technology because technology and technological expertise have tacit, country-specific qualities.

[10] Linear utility implies that people are indifferent between investing in any country, whether technologically or financially developed or not. All investments are locally financed.

[11] The innovator is not forced into price competition.

She maximizes her profit as follows:

$$\max_{\{x_{j,t}\}} p_{j,t}x_{j,t} - x_{j,t}$$

$$\text{s.t.} \qquad p_{j,t} = \alpha x_{j,t}^{\alpha-1} A_{j,t}^{1-\alpha} L_t^{1-\alpha}$$

Hence the equilibrium condition for the firm in the intermediate sector is given by:

$$x_{j,t} = \alpha^{\frac{2}{1-\alpha}} A_{j,t} L_t \tag{3.4}$$

And the equilibrium price for the variety j is calculated by replacing (3.4) in the inverse demand function:

$$p_{j,t} = \alpha^{-1} \tag{3.5}$$

which is identical for all sectors $j \in [0,1]$ and constant over time. The profit made by the intermediate monopoly in the sector j is therefore given at equilibrium by:

$$\begin{aligned} \pi_{j,t} &= (p_{j,t} - 1)\, x_{j,t} \\ &= \pi A_{j,t} L_t \end{aligned} \tag{3.6}$$

where $\pi := (1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}}$.Thus, the profits generated by each sector depend positively on the productivity of this sector. And the production of the final good at equilibrium is obtained by substituting (3.4) in (3.1) :

$$Y_t = \alpha^{\frac{2\alpha}{1-\alpha}} A_t L_t \tag{3.7}$$

and the wage level is given by :

$$w_t = \omega A_t \tag{3.8}$$

and the gross domestic production GDP is given by :

$$GDP_t = \zeta A_t L_t \tag{3.9}$$

where $\omega := (1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}}$ and ζ is given by $\zeta := (1-\alpha^2)\alpha^{\frac{2\alpha}{1-\alpha}}$ and $A_t := \int_0^1 A_{j,t}dj$ is the average level of technology (or productivity) in the economy at time t.

3.2 Financial Intermediaries

At the end of their first period of life, households invest in an innovation project. The amount invested by an innovator in sector j at date t for technology adoption is $z_{j,t}$ and the amount borrowed is $z_{j,t} - s\, w_t$ where w_t is the real wage and s the saving rate. The interest rate is noted r, and therefore the cost of repaying the loan is $(1+r)(z_{j,t} - s\, w_t)$.

I introduce imperfections in the credit market into the model as in Aghion et al. (2005). This imperfection is linked to the presence of moral hazard, which means there is a possibility that the borrower does not repay her loan by hiding the profits made. The borrower can pay a cost $h\, z_{j,t}$ proportional to the amount invested so as to avoid repaying her creditors when she succeeds. This cost is an indicator of the degree of creditor protection. However, the borrower has a probability p of being caught by the lender thus obliging her to repay her loan. Then, the total cost of being dishonesty[12] is : $h\,z_{j,t} + p\,(1+r)\,(z_{j,t} - s\,w_t)$. The borrower is prompted to choose to stay honest if :

$$h\,z_{j,t} + p\,(1+r)\,(z_{j,t} - s\,w_t) \geq (1+r)(z_{j,t} - s\,w_t) \tag{3.10}$$

which implies the following condition on the amount $z_{j,t}$ that the innovator can invest in the technology adoption project:

$$z_{j,t} \leq \frac{(1-p)(1+r)}{(1-p)(1+r)-h} s\,w_t \tag{3.11}$$

And the maximum amount that the lender would agree to lend so that the borrower chooses to be honest is given by:

$$\ell_t(p,h) = \frac{hs\,w_t}{(1-p)(1+r)-h} \tag{3.12}$$

$\ell_t(p,h)$ is proportional and increasing with the real wage w_t, increasing with the cost of being dishonest h and with the probability of being caught p, and decreasing with the interest rate r. Thus, if the financial system is less developed to the point that borrowers can cheat easily (low h) or/and it's hard to get caught (low p) then projects with the most advanced technologies and high level of investment can be constrained.

I assume that the lender can make efforts[13] to influence the probability p by spending a unit cost $C(p)$ per loan amount. The convex cost function $C(p)$ is defined such that it increases with the probability p:

$$C(p) := c\ln\left(\frac{1}{1-p}\right) \tag{3.13}$$

with $c > h$ and $c > 1+r$.
To do this, the lender resolves the problem below :

$$\max_{\{p\}} [\,p(1+r)\; + c\ln(1-p)]\,(z_{j,t} - s\,w_t) \tag{3.14}$$

So the equilibrium condition is :

$$p = 1 - \frac{c}{1+r} \tag{3.15}$$

Then, the condition (3.11) becomes:

$$z_{j,t} \leq \frac{c\,s}{c-h}\,w_t \tag{3.16}$$

$\kappa := \dfrac{c\,s}{c-h}$ is the credit multiplier which is increasing with h/c. The more expensive it is for borrowers to cheat (high h) and/or the easier it is for lenders to catch bad borrowers (low c), the higher κ will be. A higher financial development, corresponding here, therefore to a higher κ allows for more efficient control by reducing c and increasing h which relaxes the credit constraint. A highly developed financial system protects creditors by making it hard to defraud them. In an economy subject to credit constraints, an entrepreneur cannot invest more than κw_t which is constant across sectors regardless of the technology to be adopted. This can lead to an underinvestment for more advanced technologies.

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[12] I assume that the borrower's earnings $\pi_{j,t+1}$ will be sufficient to compensate the cost of being dishonest $hz_{j,t}$ and the repayment of the loan as well as the interest if caught $(1+r)(z_{j,t} - sw_t)$

[13] For example the cost of settling a financial dispute, or the cost to have access to financial information, etc.

3.3 Technological progress and productivity growth

Productivity grows as the result of innovation that allow the monopolists to access an existing technology frontier. For each intermediate sector j there is one born person at each period t who is capable of producing innovation for the next period. If she succeeds then she will become the monopolist in that sector during the period $t+1$, and her productivity will be given by $\theta\overline{A}_{j,t}+(1-\theta)A_{j,t}$ where $\overline{A}_{j,t}$ is frontier productivity in the same sector at time t and $\theta\ \in]0,1]$ is the intensity or the efficiency with which new technologies are used in the host country so that the productivity of the innovator does not jump immediatetly to the world frontier. Indeed, a country can succeed the adoption of an technology and do not use efficiently this technology. Comin & Mestieri (2018) documented that the intensity of use of technologies adopted diverge across countries and sectors. Let $\mu_{j,t}$ be the probability that adoption occurs in the sector j for the next period $t+1$. Then

$$A_{j,t+1}=\begin{cases}\theta\overline{A}_{j,t}+(1-\theta)A_{j,t} & \text{with probability } \mu_{j,t}\\ A_{j,t} & \text{with probability } 1-\mu_{j,t}\end{cases}$$

The fact that an innovator can reach $\overline{A}_{j,t}$ comes from technology transfer. Openness and connectivity of countries allow entrepreneurs to access new technologies and new ideas developed in other countries. Unlike Aghion et al. (2005)[14] and the standard Schumpeterian models which assumed that regardless of the sector the innovator adopts average technology, I assume that there is transfer of technology by sector, that is to say that when an entrepreneur succeeds in innovating in a sector, she can only catch the technological frontier in the same sector. Indeed, within a country, some sectors are less advanced and therefore easier to be adopted than others. This can influence the probability of innovation in those sectors in countries that import foreign technologies. Then, in the equilibrium the probability of innovation may not be the same in each sector. As in Aghion et al. (2005), I assume that local firms can access the frontier technology at a cost which increases with the level of productivity targeted $\theta\overline{A}_{j,t}+(1-\theta)A_{j,t}$ which means the further ahead the frontier moves in sector j, the more difficult it is to adopt its technology in that sector. The probability of innovating also increases with the amount of resources $z_{j,t}$ allocated by entrepreneurs so that the cost of an innovation is given by:

$$\frac{\lambda_{j,t}z_{j,t}}{\theta\overline{A}_{j,t}+(1-\theta)A_{j,t}}=F\left(\mu_{j,t}\right) \tag{3.17}$$

where F is a convex increasing cost function in $\mu_{j,t}$ simply defined here as : $F(\mu)=\eta\mu+\frac{\psi}{2}\mu^2$ with $\eta,\psi>0$. And $\lambda_{j,t}$ is the entrepreneurial skills. Indeed, technology adoption projects can be affected by the lack of competent resources (engineers, technicians) during the implementation phase. One of the internal factors of success innovation projects is the presence of engineers and qualified scientists within the company and the leadership provided by a leader with a high level of academic training in the field of activity. Foster & Rosenzweig (1996) and Griffith et al. (2004) gave the evidence that skills are an important determinant of a country's absorptive capacity. By learning from the previous technologies, an entrepreneur can more be likely to adopt new tech-

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[14]

$$A_{j,t+1}=\begin{cases}\overline{A}_{t+1} & \text{with probability } \mu_{j,t}\\ A_{j,t} & \text{with probability } 1-\mu_{j,t}\end{cases}$$

where $\overline{A}_{t+1}:=\int_0^1\overline{A}_{j,t+1}\,dj$ is the average of the frontier technology at time t+1.

nologies. Following Howitt & Mayer-Foulkes (2005)[15], I modeled this "learning by doing" effect through the entrepreneurial skills $\lambda_{j,t}$ which is assumed to be proportional to the productivity $A_{j,t}$, reflecting knowledge spillover :

$$\lambda_{j,t} = \lambda A_{j,t}$$

Scotchmer (1991) also modeled innovation as a cumulative process, whereby existing knowledge acts as an input in the production of new technologies. At equilibrium an innovator chooses $z_{j,t}$ in order to maximize the expected net payoff

$$\mu_{j,t}\beta\pi\left[\theta\overline{A}_{j,t} + (1-\theta)A_{j,t}\right] - z_{j,t} \tag{3.18}$$

From (3.17), the probability function of technological adoption is then a function of the sectoral proximity to the frontier $a_{j,t} := A_{j,t}/\overline{A}_{j,t}$:

$$\mu_{j,t} = -\frac{\eta}{\psi} + \left[\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda z_{j,t} a_{j,t}}{\psi\left[\theta + (1-\theta)a_{j,t}\right]}\right]^{\frac{1}{2}} \tag{3.19}$$

And the entrepreneur's problem deduced from (3.18) is given by:

$$\max_{\{\mu_{j,t}\}} \left[\left(\beta\pi - \frac{\eta}{\lambda A_{j,t}}\right)\mu_{j,t} - \frac{\psi}{2\lambda A_{j,t}}\mu_{j,t}^2\right]\left[\theta\overline{A}_{j,t} + (1-\theta)A_{j,t}\right] \tag{3.20}$$

$$\text{s.t.} \quad z_{j,t} \leq \kappa w_t$$

3.4 Equilibrium Innovation under Perfect Credit Markets

Assuming that each innovator can borrow an unlimited amount at the interest rate $r = \beta^{-1} - 1$ subject to a binding commitment to repay if the project succeeds, the problem of an innovator can be written as follows:

$$\max_{\{\mu_{j,t}\}} \left[\left(\beta\pi - \frac{\eta}{\lambda A_{j,t}}\right)\mu_{j,t} - \frac{\psi}{2\lambda A_{j,t}}\mu_{j,t}^2\right]\left[\theta\overline{A}_{j,t} + (1-\theta)A_{j,t}\right] \tag{3.21}$$

Figure 4 shows us that the probability of technology adoption increases with the host country's productivity level. The more developed the host country is in a sector, the easier it is for an entrepreneur to innovate in that sector no matter the level of advancement at the frontier of their respective sectors. In the same way, countries with a higher base productivity in a sector are more apt to adopt frontier technologies in that sector, even if there is no credit constraints.

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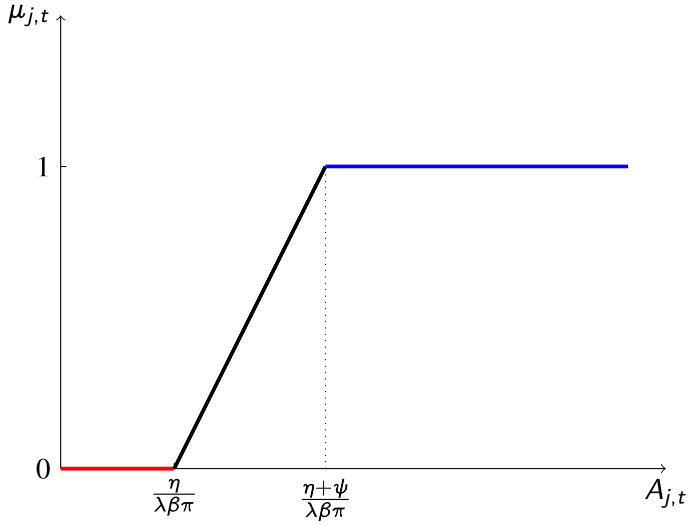
[15] with the difference that Howitt & Mayer-Foulkes (2005) assumed that $\lambda_{j,t} = \lambda A_t$ without considering the specificity of each entrepreneur in the sector in which she wants to invest.

Figure 4: The probability of adoption as a function of host country's productivity level



In the remainder of this paper, I assume that the parameters λ, ψ and η are such that the sectoral productivities are greater than $(\lambda\beta\pi)^{-1}(\eta+\psi)$. Under this asumption, without credit constraints, all countries should be able to adopt with certainty all technologies available at the frontier. In a model of endogenous productivity growth, the condition $\lambda\beta\pi A_{j,t} \geq \eta+\psi$ is much more realistic than $\lambda\beta\pi A_{j,t} < \eta+\psi$ forall t; given that productivities grow indefinitely[16]. In the following subsection, I will show that it is not so for some frontier technologies.

3.5 Equilibrium Innovation under Credit Constraints

Under credit constraints, the problem of the innovator is given by:

$$\max_{\{\mu_{j,t}\}} \left[\left(\beta\pi - \frac{\eta}{\lambda A_{j,t}}\right)\mu_{j,t} - \frac{\psi}{2\lambda A_{j,t}}\mu_{j,t}^2\right]\left[\theta\overline{A}_{j,t} + (1-\theta)A_{j,t}\right]$$

$$\text{s.t. } \mu_{j,t} \leq -\frac{\eta}{\psi} + \left[\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a_{j,t}}{\psi\left[\theta+(1-\theta)a_{j,t}\right]}\right]^{\frac{1}{2}}$$

At equilibrium, the technology adoption probability is given by :

$$\mu_{j,t}^* = \begin{cases} 1 & if\ a_{j,t} > \overline{a}_t(\kappa) \\ -\frac{\eta}{\psi} + \left[\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a_{j,t}}{\psi\left[\theta+(1-\theta)a_{j,t}\right]}\right]^{\frac{1}{2}} & if\ a_{j,t} \leq \overline{a}_t(\kappa) \end{cases}$$

where $\overline{a}_t(\kappa) = \frac{\theta(\psi+2\eta)}{2\lambda\kappa w_t - (1-\theta)(\psi+2\eta)}$ [17] is decreasing in κ. The probability of technology adoption $\mu_{j,t}^*$ increases with the proximity $a_{j,t}$ of the industry's technology to the frontier technology. Thus, when two countries engage in adopting the same technology, the country with the higher home

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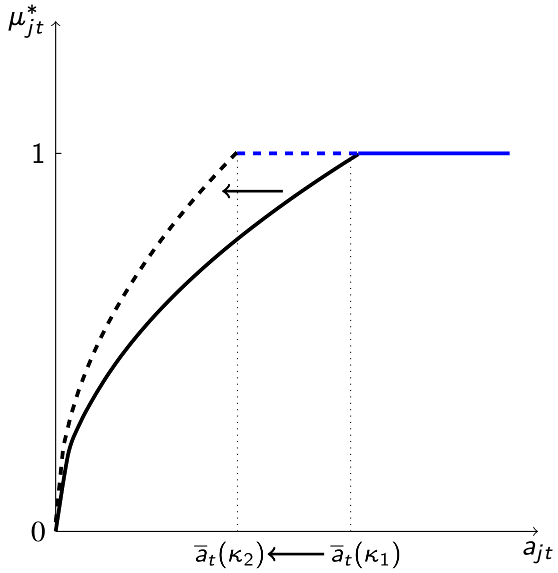
[16] Given that in the model, productivity increases over time, there is a date t_0^j from which $\lambda\beta\pi A_{j,t} \geq \eta+\psi,\ \forall t \geq t_0^j$.

[17] Since $A_{j,t} > \frac{\eta+\psi}{\lambda\beta\pi}$, it can easily be demonstrated that $\kappa w_t > \frac{(1-\theta)(\psi+2\eta)}{2\lambda}$ from the fact that $w_t = \omega A_t$ and $A_t = \int_0^1 A_{j,t}dj$.

technology has a higher probability to adopt this new technology. Figure 5 shows that financial development accelerates more the speed of diffusion of technologies for sectors that are far from the technology frontier than for sectors that are close to the frontier as stated in the Proposition 1. The level of financial development has no effect on technology adoption when the country has already reached a minimum level of development in a sector.

Figure 5: Effect of financial development on the probability of technology adoption ($\kappa_1 < \kappa_2$)



Proposition 1. *Financial development positively influences only the adoption of the most distant technologies, when the sectoral proximity is low such that :* $a_{j,t} < \bar{a}_t$.

Proof. Let's assume that $\kappa_1 < \kappa_2$ and $\mu^{(1)}_{j,t}$ (respectively $\mu^{(2)}_{j,t}$) the equilibrium probability of innovation associated with the financial development level κ_1 (respectively κ_2). we can easily show that :

$$\begin{cases} \mu^{(1)}_{j,t} < \mu^{(2)}_{j,t} & if \quad a_{j,t} < \bar{a}_t(\kappa_1). \\ \mu^{(1)}_{j,t} = \mu^{(2)}_{j,t} & if \quad a_{j,t} \geq \bar{a}_t(\kappa_1). \end{cases}$$

However if $a_{j,t} < \bar{a}_t(\kappa)$ then

$$\frac{\partial^2 \mu^*_{j,t}}{\partial \kappa \partial a_{j,t}} = \frac{\partial^2 \mu^*_{j,t}}{\partial a_{j,t} \partial \kappa}$$

$$= \frac{\dfrac{\lambda w_t \theta}{\psi \left[\theta + (1-\theta) a_{j,t}\right]^2} \left[\left(\dfrac{\eta}{\psi}\right)^2 + \dfrac{\lambda \kappa w_t a_{j,t}}{\psi \left[\theta + (1-\theta) a_{j,t}\right]} \right]}{\left[\left(\dfrac{\eta}{\psi}\right)^2 + \dfrac{2 \lambda \kappa w_t a_{j,t}}{\psi \left[\theta + (1-\theta) a_{j,t}\right]} \right]^{\frac{3}{2}}} > 0$$

■

Let $a_t := \frac{A_t}{\bar{A}_t}$ be the inverse measure of the country's distance to the technological frontier. It follows that the economic growth rate g_t under the presence of credit constraints is given by:

$$\begin{cases} g_t = \theta\left(a_t^{-1} - 1\right) & if \quad a_{j,t} \geq \bar{a}_t \quad \forall j \\ g_t < \theta\left(a_t^{-1} - 1\right) & if \quad \exists j \text{ such that } a_{j,t} < \bar{a}_t \end{cases}$$

The threshold level of κ beyond which financial development no longer influences the probability of adoption in the sector j is given by: $\underline{\kappa}_{j,t} = \frac{(2\eta+\psi)\left[\theta+(1-\theta)a_{j,t}\right]}{2\lambda w_t a_{j,t}}$. Within a country, some sectors may experience productivity growth while others may not. Let $\underline{\kappa}_t$ be defined as follow:

$$\underline{\kappa}_t = \max_{0 \leq j \leq 1} \underline{\kappa}_{j,t} \tag{3.22}$$

For countries whose level of financial development κ is such that $\kappa < \underline{\kappa}_t$, finance positively affects certain sectors and therefore growth. Beyond $\underline{\kappa}_t$ there is no effect of financial development on technology adoption in all sectors and growth.

Given that $\bar{a}_t(\kappa) = \frac{\theta(\psi+2\eta)}{2\lambda\kappa w_t - (1-\theta)(\psi+2\eta)}$ decreases over time, the curve of the dynamics of sectoral proximity to the technological frontier will converge towards the case where adoption can be achieved with certainty.In the next section, I analyze the long-run effect of financial development on the dynamics of the technology gap.

4 Sectoral productivity gap convergence and financial development

The dynamics of the secotral technology gap can be written[18] as follows:

$$a_{j,t+1} = \frac{\theta\mu_{j,t}\left(1 - a_{j,t}\right) + a_{j,t}}{1 + \bar{g}_j} \tag{4.1}$$

where $\bar{g}_j$ is the frontier sectoral productivity growth. $a_{j,t}$ will evolve according to the unconstrained dynamical equation (4.3) : $a_{j,t+1} = h_j(a_{j,t})$ when $a_{j,t} \geq \bar{a}_t$ and according to the constrained system (4.2) : $a_{j,t+1} = f_{jt}(a_{j,t})$ when $a_{j,t} < \bar{a}_t$.

$$f_{jt}(a) = \frac{a + \theta(1-a)\bar{\mu}_t(a)}{1 + \bar{g}_j} \tag{4.2}$$

$$h_j(a) = \frac{\theta}{1 + \bar{g}_j} + \frac{1-\theta}{1 + \bar{g}_j}a \tag{4.3}$$

with $\bar{\mu}_t(a) = -\frac{\eta}{\psi} + \left[\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta + (1-\theta)a\right]}\right]^{\frac{1}{2}}$. Thus $a_{j,t+1} = \min\left\{h_j(a_{j,t}),\ f_{jt}(a_{j,t})\right\}$ for all $a_{j,t} \in [0,1]$. Note that $f_{jt}(a)$ is a concave[19] function in a. $f_{jt}(0) = 0, h_j(0) = \dfrac{\theta}{1+\bar{g}_j}$ and $f_{jt}(1) = h_j(1) = \dfrac{1}{1+\bar{g}_j}$. Also $h_j'(a) = \frac{1-\theta}{1+\bar{g}_j} < 1$ at any point a and

$$\begin{cases} (1+\bar{g}_j)f_{jt}'(0) = 1 + \dfrac{\lambda\kappa w_t}{\eta} \\ (1+\bar{g}_j)f_{jt}'(1) = 1 + \dfrac{\theta\eta}{\psi} - \theta\left(\left(\dfrac{\eta}{\psi}\right)^2 + \dfrac{2\lambda\kappa w_t}{\psi}\right)^{1/2} \end{cases}$$

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[18] See Appendix A.1.1 for calculations.

[19] See Appendix A.1.2 for proof and derivations.

From where, by replacing the wage rate w_t by ωA_t we get :

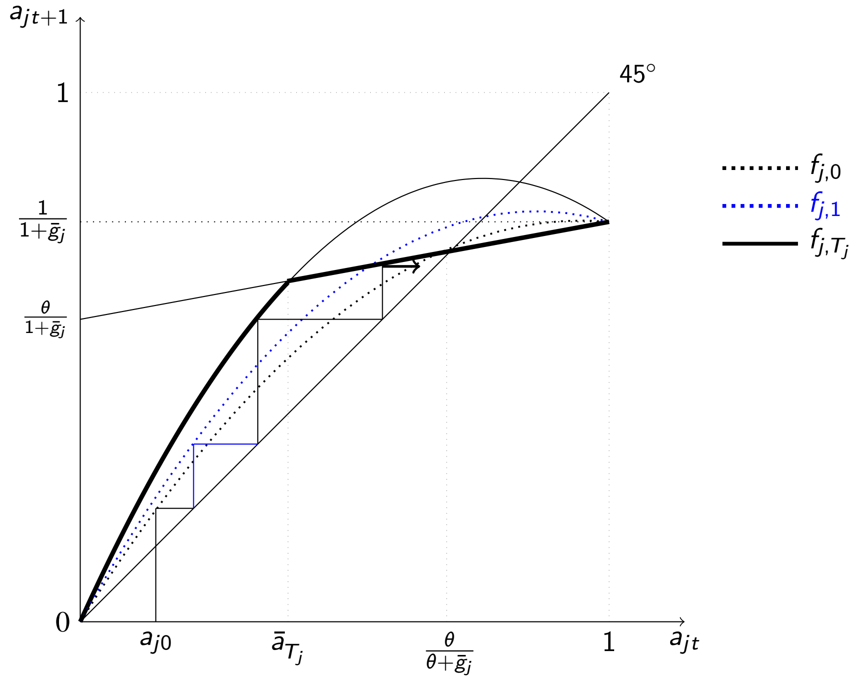
$$\begin{cases} f'_{jt}(0) \leq 1 & if \quad \kappa A_t \leq \dfrac{\eta \bar{g}_j}{\lambda \omega} \\ f'_{jt}(0) > 1 & if \quad \kappa A_t > \dfrac{\eta \bar{g}_j}{\lambda \omega} \end{cases}$$

and

$$\begin{cases} f'_{jt}(1) < \dfrac{1-\theta}{1+\bar{g}_j} & if \quad \kappa A_t > \dfrac{\psi + 2\eta}{2\lambda\omega} \\ f'_{jt}(1) \geq \dfrac{1-\theta}{1+\bar{g}_j} & if \quad \kappa A_t \leq \dfrac{\psi + 2\eta}{2\lambda\omega} \end{cases}$$

$f'_{jt}(1) < \frac{1-\theta}{1+\bar{g}_j}$ since $\kappa A_t > \frac{\psi+2\eta}{2\lambda\omega}$ [20] and $f'_{jt}(0) > 1$ for $\frac{\psi+2\eta}{2\lambda\omega} > \frac{\eta\bar{g}_j}{\lambda\omega}$. The evolution of the sectoral technology gap is then illustrated in Figure 6 below. As $f_{jt} \leq f_{jt+1}$ and $\bar{a}_t$ is decreasing with t and $a_{j,t}$ is increasing with t as long as f_{jt} is above the first bisector, there is therefore a date T_j such that $a_{j,t} \geq \bar{a}_{T_j}$ and $a_{j,t+1} = h_j(a_{j,t})\ \forall\, t \geq T_j$.

Figure 6: Sectoral productivity gap dynamic



As shown in the Figure 6, the sectoral productivity will converge asymptotically to the unconstrained steady state $a^*_j = \frac{\theta}{\theta+\bar{g}_j}$ where T_j is the convergence time in the sector j if $\theta = 1$. Countries will experience faster convergence in sectors that grow slower at the frontier (low $\bar{g}_j$), i.e., T_j increases with $\bar{g}_j$. Differences in the credit multiplier affect advanced technology adoption in the short-run but do not affect the long-run technological gap results from the fact that the effect of the upper bound placed on the amount borrowed by the entrepreneur is compensated by the increase in the country's wealth and the spillover effect on the likelihood of technology adoption. As soon as this constraint ceases to bind, then κ becomes irrelevant in determining the long-run

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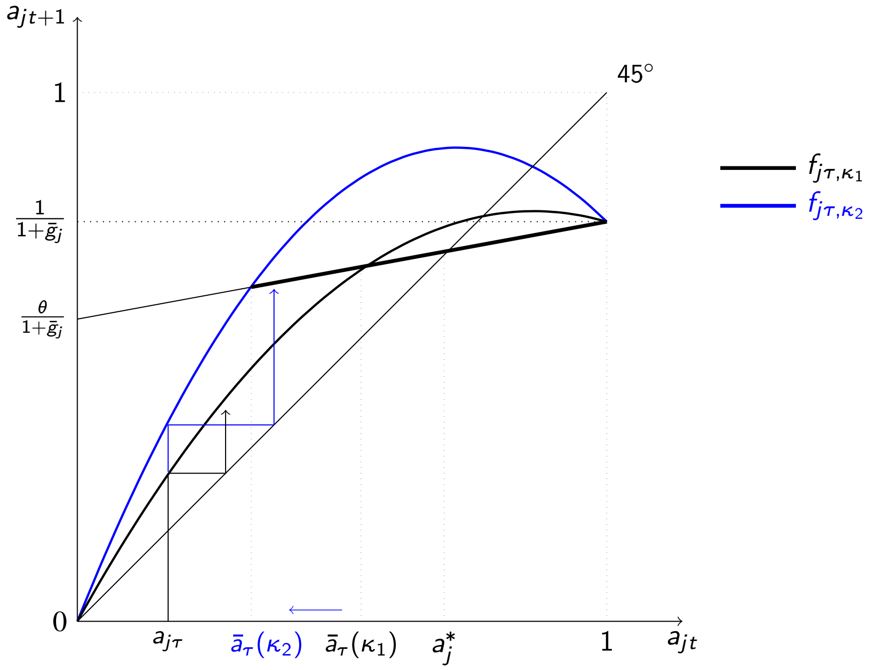
[20] $\kappa A_t > \frac{\psi+2\eta}{2\lambda\omega}$ follows from the inequality $A_{j,t} > \frac{\eta+\psi}{\lambda\beta\pi}$ as $\alpha\omega = \pi$.

Figure 7: Financial development and convergence speed : $\kappa_1 < \kappa_2$



dynamics of productivity. However, countries with high financial level of development will converge faster than countries with low financial development as proven in the proposition 2 below. Financial development affects the length of time between the invention of a new technology and the adoption of this technology, i.e., its adoption lag.

Proposition 2. *(i) Ceteris paribus, there is convergence in adoption lags between countries and sectors; financial development does not affect whether a country or a sector will converge but countries with high financial development will converge faster than low financial developed countries. (ii) Within a country, sectors that grow faster at the frontier will converge less quickly than those with a slower growth rate at the frontier.*

Proof. The reason why financial development affects positevely the speed of convergence across countries is simply because $\bar{a}_t(\kappa) = \frac{\theta(\psi+2\eta)}{2\lambda\kappa w_t-(1-\theta)(\psi+2\eta)}$ and $f'_{jt}(1)$ decrease with κ and $f'_{jt}(0)$ increases with κ. Countries with high κ will then be unconstrained more quickly as illustrated in the Figure 7 : If $\kappa_1 < \kappa_2$ then $f_{jt,\kappa_1} \leq f_{jt,\kappa_2}$ and $\bar{a}_t(\kappa_2) < \bar{a}_t(\kappa_1)$. Knowing that the unconstrained date T_j^κ is given by:

$$T_j^\kappa = \min\left\{t \geq 0 \quad \text{such that} \;\; a_{j,t} > \bar{a}_t(\kappa)\right\}$$

then $T_j^{\kappa_2} \leq T_j^{\kappa_1}$. Also note that financial development does not affect sectoral steady state value $a_j^*(\theta) = \frac{\theta}{\theta+\bar{g}_j}$.

Let now j_1 and j_2 be two sectors such that: $\bar{g}_{j_1} < \bar{g}_{j_2}$. If $\theta = 1$, let B_j be the set of all dates for which the sectoral proximity has reached its steady state's value a_j^* defined as follow:

$$B_j = \left\{t \geq 0 \quad \text{such that } a_{j,t+1} = \frac{1}{1+\bar{g}_j}\right\}$$

Then, the time of convergence T_{j_1} and T_{j_2} of the sectors j_1 and j_2 are given by : $T_{j_1} = \min\left(B_{j_1}\right)$ and $T_{j_2} = \min\left(B_{j_2}\right)$. Let us now prove that T_{j_1} is less than T_{j_2}. Given that f_{jt} decreases with $\bar{g}_j$, if these two sectors start with the same proximity to the frontier a_0 then $a_{j_1,t} > a_{j_2,t}\ \forall t$. Thus[21] $B_{j_2} \subset B_{j_1}$ and then $\min(B_{j_1}) \leq \min(B_{j_2})$. If $\theta < 1$, as h_j geometrically[22] converges to its limit $a_j^* = \frac{\theta}{\theta+\bar{g}_j}$, then the sector whose proximity to the frontier will exceed $\bar{a}_t$ first (reach h_j first) will be the first to converge. Let D_j be defined as follow:

$$D_j = \left\{ t \geq 0 \quad \text{such that} \quad a_{j,t+1} = h_j(a_{j,t}) \right\}$$

Then $D_{j_2} \subset D_{j_1}$ (details of the proof are given in the Appendix A.1.3) and $\min(D_{j_1}) \leq \min(D_{j_2})$. ■

Sectors will converge with lags to their steady-state $a_j^*(\theta)$ wich is increasing in the intensity or the efficiency θ of using new technologies. Countries that use new technologies with the same efficiency will converge to the same steady-state. That is, sectoral productivity gaps between rich and poor countries would decrease by more if the intensity of use of technology converge rather than diverge. The long-run sectoral proximity to the frontier $a_j^*(\theta)$ is also decreasing in the frontier productivity growth $\bar{g}_j$. At steady-state, the sectoral technology gap will be larger in sectors with faster growth at the frontier than in sectors with slower growth at the frontier.

5 Conclusion

Previous work examining the role of financial development in technology adoption has shown the importance of better-developed financial markets in the efficient allocation of capital among investment opportunities. No theoretical model has yet clearly shown how financial development can only drive the adoption of advanced technologies and why some countries may be successful in adopting advanced technologies and others not.

By focusing on the differences between the least advanced and the most advanced technologies in the technology adoption process, this paper builds a Schumpeterian endogenous growth model in which technological skilled entrepreneurs can earn monopoly profits by adopting better technologies from the world frontier and in which imperfections in the financial market can lead to the misallocation of capital among technology adoption projects. The model is an extension of Aghion et al. (2005) with two novel features. First, each entrepreneur adopts from the frontier the technology of the sector in which she wishes to innovate, unlike the standard models in which all entrepreneurs opt for the same technology if they are successful. Second, the model takes into account the skills of the entrepreneurs and the intensity of using new technologies.

The predictions of the model provide another explanation of the role played by the financial system on technology adoption. They show that the financial development is necessary for sustaining adoption of the most advanced technologies. However, this effect is non-existent for countries that have achieved a minimum level of financial development. The model also predicts no differential effect of financial depth on the adoption of the less advanced or the closest technologies. These implications were tested by estimating a cross-country panel technology regression with an interaction term between financial intermediation and the country's sectoral productivity relative to US. As predicted, the coefficient of this term is positive and significant implying that financial development plays a more important role in the adoption of more distant technologies. The model also implies that financial development accelerates the convergence of the sectoral distance to the technological frontier towards the stationary state and countries converge quickly in the sectors

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[21] See Appendix A.1.3 for more demonstration details.

[22] $\left| a_{jt} - \frac{\theta}{\theta+\bar{g}_j} \right| = \left(\frac{1-\theta}{1+\bar{g}_j} \right)^{t-T_j} \left| a_{jT_j} - \frac{\theta}{\theta+\bar{g}_j} \right|$ with $\frac{1-\theta}{1+\bar{g}_j} < 1$

which grow less quickly at the frontier. A main implication of the model is the convergence of sectoral productivity conditional on the intensity of using new technologies. Finance does not play a role on the long-run technological gap, but only on the speed of convergence.

There are several dimensions along which it will be important to extend the analysis carried out here. For example, this study highlights financial depth and the level of productivity in different sectors as determinants of the differences in technology adoption in developing countries. Next steps in this research program could be, first, to dig further into the role of Foreign Direct Investment (FDI) as a substitute for lending to local entrepreneurs knowing that Alfaro et al. (2004) and Suliman & Elian (2014) have shown that FDI has an effect on economic activity only when the financial system is efficient, and, second, to analyze how finance and initial sectoral productivity levels, through technological adoption, can explain the differences between the paths and rates of structural change that exist between developing countries and with developed countries.

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A Appendix

A.1 Mathematical demonstrations

A.1.1 Dynamics of the sectoral productivity

$$\begin{aligned} A_{j,t+1} &= \mu_{j,t}\left[\theta\overline{A}_{j,t} + (1-\theta)A_{j,t}\right] + (1-\mu_{j,t})A_{j,t} \\ &= \theta\mu_{j,t}\overline{A}_{j,t} + (1-\theta\mu_{j,t})A_{j,t} \end{aligned} \tag{A.1}$$

- If $a_{j,t} < \bar{a}_t$ then :

$$a_{j,t+1} = \theta\bar{\mu}_{j,t}\frac{\overline{A}_{j,t}}{\overline{A}_{j,t+1}} + (1-\theta\bar{\mu}_{j,t})\frac{A_{j,t}}{\overline{A}_{j,t+1}}$$

with $\bar{\mu}_{j,t}(a) = -\frac{\eta}{\psi} + \left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{\frac{1}{2}}$. After a few manipulation, one gets :

$$\begin{aligned} a_{j,t+1} &= \theta\bar{\mu}_{j,t}\frac{1}{1+\bar{g}_j} + (1-\theta\bar{\mu}_{j,t})\frac{a_{j,t}}{1+\bar{g}_j} \\ &= f_{jt}(a_{j,t}) \end{aligned}$$

with $f_{jt}(a) = \frac{a + \theta\bar{\mu}_{j,t}(1-a)}{1+\bar{g}_j}$.

- If $a_{j,t} \geq \bar{a}_t$ then $a_{j,t+1} = \frac{\theta}{1+\bar{g}_j} + \frac{1-\theta}{1+\bar{g}_j}a_{j,t}$. Note that w_t is increasing with t.

A.1.2 Variation study of f_{jt}

$$(1+\bar{g}_j)f_{jt}(a) = a + \theta(1-a)\left[-\frac{\eta}{\psi} + \left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{\frac{1}{2}}\right]$$

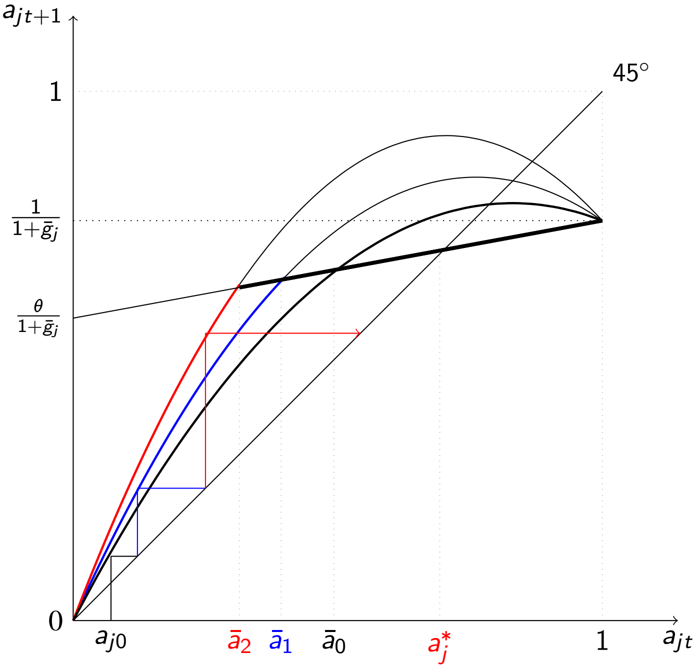
$$\begin{aligned} \Longrightarrow (1+\bar{g}_j)f_{jt}^{'}(a) = 1 + \frac{\theta\eta}{\psi} - \theta\left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{\frac{1}{2}} + \theta^2(1-a) \\ \times\frac{\lambda\kappa w_t}{\psi\left[\theta+(1-\theta)a\right]^2}\left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{-\frac{1}{2}} \end{aligned} \tag{A.2}$$

$$\begin{aligned} \Longrightarrow (1+\bar{g}_j)f_{jt}^{''}(a) = -\frac{2\theta^2\lambda\kappa w_t}{\psi\left[\theta+(1-\theta)a\right]^2}\left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{-\frac{1}{2}} \\ -\frac{2\theta(1-a)(1-\theta)\lambda\kappa w_t}{\psi\left[\theta+(1-\theta)a\right]^3}\left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{-\frac{1}{2}} \\ -\frac{\theta^2(1-a)(\lambda\kappa w_t)^2}{\psi^2\left[\theta+(1-\theta)a\right]^4}\left(\left(\frac{\eta}{\psi}\right)^2 + \frac{2\lambda\kappa w_t a}{\psi\left[\theta+(1-\theta)a\right]}\right)^{-\frac{3}{2}} \end{aligned} \tag{A.3}$$

$f''_{jt} < 0 \implies f_{jt}$ is concave in a. Also

$$\begin{cases} (1+\bar{g}_j)f'_{jt}(0) = 1 + \dfrac{\lambda\kappa w_t}{\eta} \\ (1+\bar{g}_j)f'_{jt}(1) = 1 + \dfrac{\theta\eta}{\psi} - \theta\left(\left(\dfrac{\eta}{\psi}\right)^2 + \dfrac{2\lambda\kappa w_t}{\psi}\right)^{1/2} \end{cases}$$

Figure 8: Sectoral productivity gap dynamic : $\kappa > \tilde{\kappa}_0$



A.1.3 Demonstration details of Proposition 2.

Let us proove that $B_{j_2} \subset B_{j_1}$.
If $\tau \in B_{j_2}$ then $a_{j_2,\tau} = \dfrac{1}{1+\bar{g}_{j_2}}$.

$$\begin{aligned} a_{j_2,\tau} = \frac{1}{1+\bar{g}_{j_2}} &\implies a_{j_2,\tau-1} \geq \bar{a}_{\tau-1} \\ &\implies a_{j_1,\tau-1} > \bar{a}_{\tau-1}\,, \quad \text{for} \quad a_{j_1,t} > a_{j_2,t} \;\; \forall t \\ &\implies a_{j_1,\tau} = \frac{1}{1+\bar{g}_{j_2}} \\ &\implies \tau \in B_{j_1}. \end{aligned}$$

From where $B_{j_2} \subset B_{j_1}$ and $\min(B_{j_2}) \geq \min(B_{j_1})$.

Let proove now that $D_{j_2} \subset D_{j_1}$ in general, i.e. $\forall\theta \in (0,1]$.
If $\tau \in D_{j_2}$ then $a_{j_2,\tau+1} = h_{j_2}(a_{j_2,\tau})$ and $a_{j_2,\tau} \geq \bar{a}_\tau \implies a_{j_1,\tau} > \bar{a}_\tau$. So, $a_{j_1,\tau+1} = h_{j_1}(a_{j_1,\tau})$ and $\tau \in D_{j_1} \implies D_{j_2} \subset D_{j_1}$.

A.1.4 Section ?? : Test of significance

To test the significance of the marginal effect of financial development on technology adoption given a level of proximity to the frontier, I perform the following test:
$H_0 : \beta_1 + \beta_3 * dist_c = 0$ vs $H_1 : \beta_1 + \beta_3 * dist_c \neq 0$
The Student's test statistic is given by:

$$Z = \sqrt{T} \frac{\hat{\beta}_1 + \hat{\beta}_3 * dist_c - (\beta_1 + \beta_3 * dist_c)}{\sqrt{var(\hat{\beta}_1) + dist_c^2 * var(\hat{\beta}_3) + 2dist_c * cov(\hat{\beta}_1, \hat{\beta}_3)}}$$

Since the data size is large enough, under the null hypothesis, the Z statistic follows a centered and reduced normal distribution. Thus the null hypothesis is rejected if and only if:

$$T \left(\hat{\beta}_1 + \hat{\beta}_3 * dist_c \right)^2 \geq z_{\alpha/2}^2 \left[var(\hat{\beta}_1) + dist_c^2 * var(\hat{\beta}_3) + 2dist_c * cov(\hat{\beta}_1, \hat{\beta}_3) \right] \tag{A.4}$$

where $z_{\alpha/2} = F^{-1}\left(1 - \frac{\alpha}{2}\right)$ and F is the cumulative function of a standard normal distribution and T is the number of observations.

A.2 Data Appendix

Table 4: Variables used in panel data regresssions

Variables	Description	Source	Period covered
GDP per capita	Real GDP per capita	World Bank (2021)	1960-2020
Productivity	Value added per worker	World Bank (2021)	1991-2019
Financial development	% GDP of total private credit	World Bank (2021)	1960-2020
Population	Total of residents	World Bank (2021)	1960-2020
Human Capital	Human Capital Index	Penn World Table version 10.0	1960-2019
Governance	Traditions and Institutions	WGI (2021)	1996-2020
Geography	Lattitude	Geodata95 (website)	
Technology data	See Table 1	HCCTAD (Comin & Hobijn (2004))	1750-2003

All data are aggregated to 5-year time periods spanning 1991-2003.

WGI : Worldwide Governance Indicators

HCCTAD : Historical Cross-country Technology Adoption Data

Description of Governance variables. Governance is defined as the set of traditions and institutions by which authority in a country is exercised. This includes :
(1) the process by which governments are selected, monitored and replaced,
(2) the capacity of the government to effectively formulate and implement sound policies, and
(3) the respect of citizens and the state for the institutions that govern economic and social interactions among them.

The WGI (World Governance Indicators) measure six broad dimensions of governance:

1. **Voice and Accountability (VA)** – capturing perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.
2. **Political Stability and Absence of Violence/Terrorism (PV)** – capturing perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism.
3. **Government Effectiveness (GE)** – capturing perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.
4. **Regulatory Quality (RQ)** – capturing perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
5. **Rule of Law (RL)** – capturing perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.
6. **Control of Corruption (CC)** – capturing perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.

A.3 Regression Outputs Appendix

Table 5: Cross-country regressions, dependent variable : log technology diffusion per capita

	Type of technology					
	elecprod	tractor	internet	telephone	harvester	vehicle
Loans/GDP	-0.006***	-0.002	0.002	-0.006	-0.014	-0.018***
	(0.003)	(0.715)	(0.616)	(0.109)	(0.168)	(0.004)
Sectoral proximity (in log)	0.154	0.377	0.737***	0.344*	0.447	0.457
	(0.407)	(0.191)	(0.000)	(0.096)	(0.307)	(0.216)
Loans/GDP×Proximity	-0.008***	-0.003*	-0.009***	-0.010***	-0.010***	-0.007**
	(0.000)	(0.081)	(0.001)	(0.001)	(0.002)	(0.027)
GDP per capita	0.758***	0.367	0.557***	0.609***	0.530	0.582**
	(0.001)	(0.311)	(0.001)	(0.001)	(0.296)	(0.033)
Human capital	1.137***	1.067***	0.391*	0.979***	1.173**	0.615**
	(0.001)	(0.004)	(0.073)	(0.000)	(0.023)	(0.023)
Observations	85	106	99	54	82	60
R-squared	0.881	0.691	0.890	0.893	0.579	0.811

(1) All data sources are discussed in the Data Appendix A.2 and robust p-values are listed in parentheses. (2) *elecprod*: KwHr produced, *tractor*: number in operation, *internet*: number of users, *telephone* : number connected, *harvester*: number, *vehicle* : number of commercial vehicles. in operation. (3) *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: Technology adoption, financial development and sectoral proximity to the frontier (1991-2003)

	log technology diffusion per capita : average over 1991-2003					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Explanatory variables are average over the period 1991-2003.						
Loans/GDP	0.005***	0.000	-0.002	0.009	-0.007	-0.014
	(0.008)	(0.826)	(0.249)	(0.647)	(0.738)	(0.504)
Sectoral proximity (in log)	1.171***	0.261***	0.256***	0.242**	0.267**	0.275***
	(0.000)	(0.004)	(0.007)	(0.017)	(0.010)	(0.008)
Loans/GDP × Proximity	-0.005***	-0.005***	-0.005***	-0.004*	-0.005**	-0.005**
	(0.000)	(0.000)	(0.000)	(0.077)	(0.017)	(0.018)
GDP per capita (in log)		0.837***	0.630***		0.620***	0.516***
		(0.000)	(0.000)		(0.000)	(0.000)
GDP per capita × Finance				-0.001	0.000	0.004
				(0.659)	(0.814)	(0.105)
Human capital			0.668***		0.669***	0.937***
			(0.000)		(0.000)	(0.000)
Human capital× Finance						-0.009***
						(0.004)
Observations	1,159	1,159	1,105	1,159	1,105	1,105
R-squared	0.946	0.953	0.957	0.953	0.957	0.957
Panel A: Explanatory variables are variables in 1991.						
Loans/GDP	0.008***	0.000	-0.005**	0.004	-0.011	-0.011
	(0.000)	(0.855)	(0.014)	(0.903)	(0.719)	(0.711)
Sectoral proximity	0.997***	0.222**	0.238***	0.214*	0.251**	0.251**
	(0.000)	(0.020)	(0.009)	(0.064)	(0.021)	(0.021)
Loans/GDP×Proximity	-0.005***	-0.006***	-0.006***	-0.006*	-0.007**	-0.007**
	(0.000)	(0.000)	(0.000)	(0.081)	(0.045)	(0.042)
GDP per capita		0.841***	0.569***	0.848***	0.558***	0.558***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP per capita×Finance				-0.000	0.001	0.001
				(0.912)	(0.849)	(0.880)
Human capital			0.862***		0.862***	0.862***
			(0.000)		(0.000)	(0.000)
Human capital× Finance						0.000
						(1.000)
Observations	710	710	688	710	688	688
R-squared	0.952	0.960	0.963	0.960	0.963	0.963
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1