The Impact of Financial Frictions on Technological Adoption and Economic Growth: A Quantitative Analysis

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Abstract

There is evidence in the literature for different technologies utilized across countries with different levels of financial development. So, this paper studies the technological adoption channel based on a menu of technologies with varying adoption costs: unproductive, intermediate, and productive. Studying relevant questions on the effects of financial frictions on technological adoption and aggregate macroeconomic variables. Quantitative results show the model replicating features shown in the collated micro-level data set and that financial friction plays a considerable role through the technological adoption channel. More importantly, the addition of the intermediate technology provides higher levels of aggregate consumption, output, and TFP.

JEL Classification: E21, E44, F41, G32, O11, O33

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1 Introduction

Considerable evidence has shown different technological levels across countries and within a single country. Across countries, papers like Comin and Hobijn (2010) and Cole, Greenwood, and Sanchez (2016) discuss and provide evidence for differences in technology levels among countries. Comin and Hobijn (2010) detail an adoption lag of 45 years to show the disparity of technology levels across countries, while Cole, Greenwood, and Sanchez (2016) mention three countries with different technology. Within a single economy, Lissoni (2000) describes different technologies. Lissoni (2000) describes the existence of an intermediate technology that purposefully lags behind the technological frontier to provide lower adoption costs to its potential adopters. De Vries and Koetter (2011) show that varying Information and Communication Technology (ICT) adoption levels lead to varying technologies among Chilean firms. Complementing this notion of different technology regime by De Vries and Koetter (2011), evidence from "Innovate Indonesia Unlocking Growth Through Technological Transformation" indicate that manufacturing firms have three different levels of technology. Specifically, the technology regime of manufacturing firms in Indonesia comprises 6 percent in the advanced level, 30 percent in the intermediate level, and 64 percent in the basic level.

Providing another interpretation of this intermediate technology is the notion of appropriate technology mentioned in Schumacher (1975). Schumacher explains that developing countries would prefer an appropriate technological level technologies that are more suitable for their financial environment. Basu and Weil (1998) further explore this appropriate technology idea in their model, with a follower country only being able to adopt a technology if the capital intensity of the new technology falls within the neighborhood of its existing technologies. Hence, making way to the idea of a more suitable form of technology over the frontier technology for certain countries.

Given this overarching theme of an intermediate technology, an interesting analysis would be to uncover the role of a country's financial development on its subsequent technological adoption. Relevant to this notion is the paper by Cole, Greenwood, and Sanchez (2016) that explains how a country's financial market determines the quality of projects entrepreneurs take on and how it influences its corresponding technology adoption. This technological adoption, in turn, impacts the country's income and Total Factor Productivity (TFP) level. Similarly, in their two-sector model, Midrigan and Xu (2014) show that the impact of financial friction on adopting technology in the modern sector is more significant than its impact through the misallocation of capital across plants for explaining TFP. In Midrigan and Xu (2014), they emphasize the technological adoption channel. Thus, this paper will zoom into this technological adoption channel to investigate the results of an intermediate technology being introduced into the technology ladder. Moreover, uncovering relevant questions on the effects of financial frictions on aggregate variables of interest, such as TFP, output, and consumption. Additionally, providing analysis on the effects when the collateral constraint tightens or loosens for a single economy and a cross-country comparison.

This paper proposes a model incorporating heterogeneous producers with different productivity and wealth levels to delve into these relevant questions. As adopting technologies would require the firm to pay a royalty cost, not all firms have sufficient credit to adopt. To raise capital, each of these producers will obtain loans through a collateral constraint based on the amount of tangible and intangible capital it has. Besides borrowing, producers can also raise capital through one-time equity issuance. For the low wealth firms in the economy, it would still require time to obtain the funds needed to subsequently adopt a higher level of technology. So in the model, a more affordable variety of technology, intermediate technology, is also incorporated in the production sector. Thus, there are unproductive, intermediate, and productive producers in the production sector that have an additional A_u, A_i, and A_p productivity respectively, where $A_u < A_i < A_p$. Adopting a higher level of technology is associated with a higher cost, i.e $\kappa_u < \kappa_i < \kappa_p$.

In order to achieve the quantitative results of this paper, the model is disciplined through calibrating mainly with data moments obtained from the micro-level data. Here micro-level data for economies with different levels of financial markets were utilized, where the US represents one with the highest financial development, followed by Chile and then Egypt. The primary analysis starts with Chilean firms where important data moments such as cross-country TFP and the debt and equity market were used for calibration. The quantitative results show that financial friction plays a huge role through the technological adoption channel when an intermediate technology is introduced. A higher level of financial development is related to producers adopting more productive technologies, where the US has the most productive producer, Chile has the most intermediate technology producers, and Egypt has the most producers with entry-level technology. This pattern of technological adoption for the different economies also expresses how the model does a great job replicating the empirical observation about the TFP patterns across Egypt, Chile, and the US. Whereby, most Chilean firms tend to adopt the technology that provides an intermediate TFP level relating to the data observation of Chile having a majority firms TFP level below the majority firm TFP level of the US and above the majority firm TFP level of Egypt. More importantly, for the quantitative results, the addition of an intermediate technology for developing or emerging economies provides higher levels of aggregate consumption, output, and TFP. As for developed economies, intermediate technologies can help buffer the losses from the production process, specifically aggregate TFP and output during bad times.

Related Literature

A vast set of literature discusses alternative forms of technology, such as Cole, Greenwood, and Sanchez (2016), Comin and Hobijn (2010), De Vries and Koetter (2011), and Lissoni (2000). Comin and Hobijn (2010) uncover technological adoption lags to show disparate technologies across countries, while Cole, Greenwood, and Sanchez (2016) introduce the possibility of an intermediate technology for some countries. Similarly, Lissoni (2000) describes intermediate technology as not as productive as the technological frontier but allows users to pay a lower cost. De Vries and Koetter (2011) provide an example with Chilean firms having varying ICT (information and communication Technology) adoption levels. This paper draws upon the notion of an additional intermediate technology mentioned in this literature but establishes a different theoretical model with collateral constraint and has misallocation of capital.

With regards to the literature that is related to the theoretical model of this paper, Amaral and Quintin (2010), Buera, Kaboski, and Shin (2011), Buera and Shin (2013), Caselli and Gennaioli (2013), and Midrigan and Xu (2014) provide a relevant modeling structure. These papers focus on the crucial impact of financial friction on economic development. Amaral and Quintin (2010) find that poor enforcement prevents productive allocations from being allocated efficiently. Buera, Kaboski, and Shin (2011) incorporate a two-sector theoretical model where the larger sector requires more financing. Because of the larger sector's financial dependence, it is more susceptible to financial frictions that will impact the overall economy. As for Buera and Shin (2013), their model analyses the role of initial resource misallocation and financial frictions to explain the time paths of aggregate variables such as Gross Domestic Product, TFP, and investment rates. Financial friction in their paper, which is a collateral constraint, can affect the level of GDP of developing economies taking the US as given. Next, Caselli and Gennaioli (2013) show that a transfer of ownership to the next generation to manage the family firm, also known as a dynasty type management, causes cross-country differences due to financial frictions. Midrigan and Xu (2014) paper has modern and traditional sectors. Producers in the modern sector face a financing constraint and use borrowing to adopt more productive technology. Therefore, these papers show that financial frictions have sizable effects on aggregate efficiency without analyzing an intermediate technology that this paper goes into.

In line with the theoretical literature on financial development, numerous papers provide empirical support for the relationship between financial development and economic growth. For one, King and Levine (1993) examine four different measures of financial indicators and show that financial development stimulates economic growth for 80 countries over 1960-1989. Similarly, Benhabib and Spiegel (2000) showcase a correlation between financial development indicators and the growth of variables such as total factor productivity and investment. Rajan and Zingales (1998) and Beck and Levine (2002) focus on more financially dependent sectors in countries with well-developed financial markets and show that these sectors grow much faster. To deal with the issue of simultaneity bias, papers such as Levine (1999) and Levine, Loayza, and Beck (2000) utilize a legal origin measure constructed in the Laporta et al. (1998) as instrumental variables. These legal origin instruments show that countries that safeguard the rights of external investors tend to have better financial development that translates to better economic growth. While these papers provide the background that a more developed financial level tends to lead to a country having better economic growth, this paper tries to uncover this relationship through firm-level technological adoption.

Another set of literature that dives into firm-level technological-related research questions are papers such Benhabib, Perla, and Tonetti (2014), Perla and Tonetti (2014), and Lucas and Moll (2014). Benhabib, Perla, and Tonetti (2014) showcase a mechanism where firms decide how much to spend on imitation and innovation. In their paper, the firm chooses how much distance they want to close with the leader. Specifically, the firm decides whether to go all the way up at once or slowly. This behavior causes the productivity distribution to move. Lastly, Perla and Tonetti (2014) and Lucas and Moll (2014) show growth in an economy led by imitation by low productivity firms.

2 Empirical Motivation

This section provides some empirical motivation for the paper. The first point that it establishes is to observe the correlation between TFP and the level of financial development, which could also hint at countries adopting different forms of technology. Secondly, a regression is performed for technological adoption on the level of financial development to provide some idea of its relationship.

In terms of the data used, a combination of Macro and Micro level data was obtained for this section's first point of investigation. The TFP distributions for comparison among the US, Chile, and Egypt economies were derived from firm-level data set for the manufacturing industry. Further details for these Macro and Micro level data sets are explained in the appendix. As for the second point this section makes, data for the technological adoption variable is obtained from the cross-country historical adoption (CHAT) dataset provided by Comin and Hobijn (2009). This CHAT dataset is then merged with data on the corresponding economy's level of financial development, where details for this merged data set are explained in the appendix. The regression analysis that follows this second point of investigation is performed for a selected set of technologies in the manufacturing sector and a representative good of the manufacturing industry, crude steel.

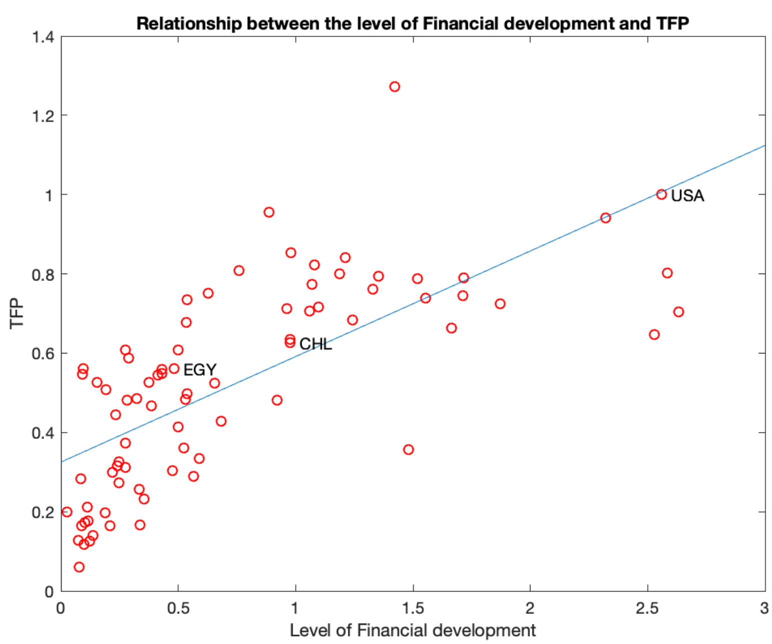
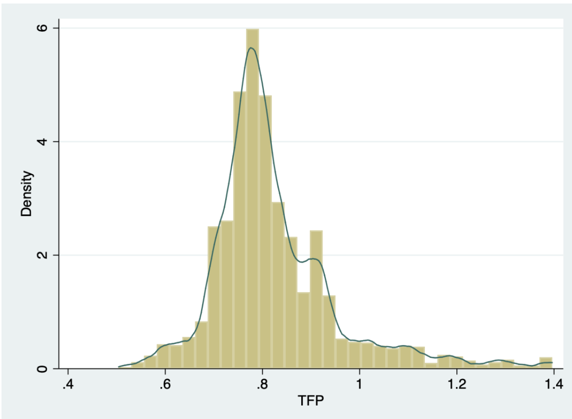
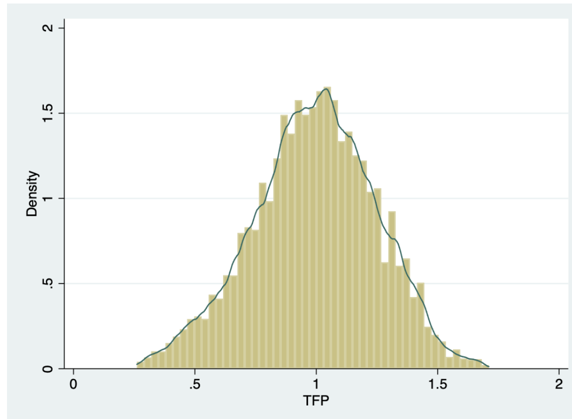


Figure 1: Relationship between level of financial development and the country's TFP

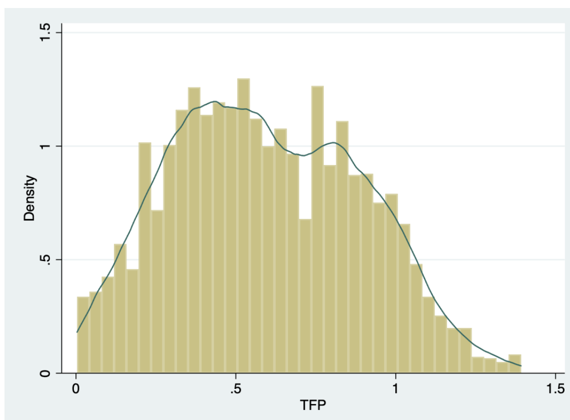
Having collated the necessary data set, figure 1 presents a scatterplot that shows the relationship between a country's level of financial development(relevant to θ variable in the collateral constraint of the theoretical model) with its TFP levels. The figure shows that both the TFP level and level of financial development are positively related, with the least square line sloping positively upwards.



(a) Chile



(b) The US



(c) Egypt

Figure 2: TFP Distribution Across Different Economies

Figure 2 shows the TFP distribution for three different economies, Chile, the US, and Egypt. The analysis of these three economies is to compare the TFP between economies that exhibit different levels of financial development. As highlighted in figure 1, the US has the most developed financial market, followed by Chile, and the least developed of the three is the financial market in Egypt. First, (a) shows that the distribution in Chile is more filled up in the middle. Then, the subplot in (b) suggests that the US has a relatively small left tail but a relatively thick right tail. The highest point for the US is above 1.5. Subsequently, the subplot in (c) characterizes

Egypt with a fat left tail and a thin right tail. Hence the comparison shown in figure 2 shows that economies with different levels of financial development have varying TFP levels, possibly due to each country adopting a different technology.

More specifically, the cross-country comparison of figure 2 shows that majority of the firms have an intermediate TFP level within the 0.8 region. Compared to the intermediate 0.8 TFP level region for the US, which is a more developed financial market, it has a lower density. With the lowest financial development of these three economies, Egypt exhibits a modest and not the most significant share in this intermediate 0.8 TFP level region. This feature is also shown in the quantitative results of the model expresses varying levels of intermediate technology adoption where only the majority of producers of the Chilean economy choose to adopt the intermediate technology that relates to this intermediate TFP region.

To supplement the analysis in Figures 1 and 2, Table 1 reports the results of a panel regression. A regression based on a simple TFP regression equation below is performed solely for analytical and illustrative purposes.

$$\text{TFP}_{c,t} = \beta_1 * \text{FD}_{c,t} + \text{Fixed Effects} + \text{Constant} + \varepsilon_{c,t}$$

Variables	(1) OLS	(2) Country FE	(3) Year FE	(4) Country and Year FE
Level of Financial Development	0.284***	0.0406**	0.283***	0.0541***
	(0.0238)	(0.0177)	(0.0244)	(0.0183)
Constant	0.611***	0.722***	0.612***	0.738***
	(0.0126)	(0.00825)	(0.0128)	(0.0132)
Observations	831	831	831	831
R-squared	0.146	0.007	0.142	0.091
Number of countries	46	46	46	46
Number of years	22	22	22	22

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

Table 1: Panel Regression of Country's TFP on its Level of Financial Development

where FD represents the Level of Financial Development, and subscript c=country, and t=time.

Table 1 shows that the coefficients related to the level of financial development are positive in all cases and ranges from 0.0406 to 0.284. Also, the coefficients are significantly different from zero for a significant value of 5 percent.

Extending further, a simple technological adoption regression equation below is also performed to delve into the second point of analysis in this section.

$$\text{TAM}_{i,c,t} = \beta_1 * \text{FD}_{c,t} + \text{Fixed Effects} + \text{Constant} + \varepsilon_{ict}$$

where TAM represents Technology Adoption Measure, FD represents the Level of Financial Development and subscript i= technology, c=country, and t=time.

Variables	(1) OLS	(2) Country FE	(3) Year FE	(4) Country and Year FE
Level of Financial Development	0.259***	0.0797***	0.261***	0.0514*
	(0.0295)	(0.0278)	(0.0303)	(0.0268)
Constant	-0.0293*	0.0566***	-0.0304*	0.0812***
	(0.0163)	(0.0135)	(0.0166)	(0.0155)
Observations	469	469	469	469
R-squared	0.141	0.019	0.140	0.241
Number of countries	44	44	44	44
Number of years	13	13	13	13

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

Table 2: Panel Regression of a sum of measures for different technologies in a country on its Level of Financial Development

Table 2 shows that the coefficients related to the level of financial development are positive in all cases and ranges from 0.0797 to 0.261. Also, the coefficients are significantly different from zero for a significant value of 1 percent for columns (1)-(3) and a significant value of 10 percent for column (4). Table 2 provides a measure of technological adoption over a combination of different technologies associated with the manufacturing industry. Specifically, technologies related to the production of steel, cars, both commercial and passenger, and agriculture tractors are all relevant to the manufacturing industry.

To zone in a particular technology such as crude steel production typical in the manufacturing industry, table 3 exhibits a similar analysis to table 2. Specifically, the coefficients for the level of financial development range over positive values of 0.111 to 0.339. Furthermore, these coefficients are significant even at a significant value of 1 percent.

To sum up, cross country-wise, there is a significant and positive correlation between TFP and the level of financial development. Additionally, the starkly different TFP distributions could point to countries having adopted different levels of technology. Lastly, a regression of technological adoption on the level of financial development shows a significant and positive correlation to imply that economies with more developed financial markets tend to have higher levels of technological adoption.

Variables	(1) OLS	(2) Country FE	(3) Year FE	(4) Country and Year FE
Level of Financial Development	0.333***	0.113***	0.339***	0.111***
	(0.0400)	(0.0233)	(0.0414)	(0.0259)
Constant	-0.0133	0.0896***	-0.0160	0.0933***
	(0.0216)	(0.0110)	(0.0222)	(0.0142)
Observations	367	367	367	367
R-squared	0.159	0.067	0.159	0.097
Number of countries	40	40	40	40
Number of years	11	11	11	11

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

Table 3: Panel Regression of the Country's Crude steel production (in metric tons) on its Level of Financial Development

3 Theroretical Model

The model is close to that in Midrigan and Xu (2014) and is related to models from Buera and Shin (2013) and Buera, Kaboski, and Shin (2011). These papers incorporate capital and a collateral constraint. Hence the structural model shown in this paper is similar and based on papers in this literature.

In the model of this paper, there exists a measure one of workers and a measure N_t of producers in the production sectors. Each worker supplies $(\psi^t \eta_t)$ efficiency units of labor, where η_t represents the worker's idiosyncratic efficiency and evolves according to a finite-state Markov process. [1] The efficiency of labor and the measure of producers grows over time at a constant rate ψ(growth rate variable). With producer growth, it implies the assumption that a measure $(\psi - 1)N_t$ of producers enter the economy at the end of period t. Producers that just enter receive a transitory productivity A_e. $A_{e,t}$ is a transitory productivity component that evolves over time according to a finite-state Markov process on E = $\{A_{e,1},...,A_{e,H}\}$ with transition probabilities $f_{i,j}$ = Pr($A_{e,t}$ = $A_{e,i}$,$A_{e,t+1}$ = $A_{e,j}$). Furthermore, it is assumed that entering producers will draw this productivity component A_e from the stationary distribution f, which is denoted $\bar{f}_i$. [2]

Entering producers pay zero fixed cost, which means that κ_u=0. Producers can obtain more funds from borrowing or one-time equity issuance. Borrowing, B_{t+1}, is based on a collateral constraint where producers with different technology levels will face a different specification. A one-time issuance of equity occurs when producers first enter the production sector as unproductive produces. There are unproductive, intermediate, and productive producers in this production sector. These unproductive, intermediate, and productive producers have an additional A_u, A_i, and A_p productivity respectively, where $A_u < A_i < A_p$. Adopting a higher level of technology is associated with a higher cost, i.e $\kappa_u = 0 < \kappa_i < \kappa_p$.[3]

[1]This worker efficiency process is helpful for computational purposes as it helps to pin down the precautionary savings motive and, in turn, the equilibrium interest rate from the asset market clearing condition defined in the balanced growth equilibrium

[2]Having the feature of a productivity shock and producers entering the economy at the end of period t avoids the scenario where the distribution of producer's net worth converges into a mass point. Hence, this model's producers' net worth will not converge to a mass point. This avoidance of a mass point convergence is also mentioned in Banerjee and Moll (2010) and Midrigan and Xu (2014).

[3]Even though the unproductive producer faces a lower cost of upgrading to the intermediate technology over the productive technology, intermediate producers that eventually decide on adopting the frontier technology will face the same cost as unproductive workers that choose to adopt this frontier technology directly.

3.1 Model

3.2 Workers

The worker maximizes his lifetime utility:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t log(c_t)$$

The budget constraint for the worker [4]:

$$c_t + a_{t+1} + \int S^i_{t+1} Q^i_t di = (1+r)a_t + W\psi^t \eta_t + \int S^i_t (Q^i_t + \pi^i_{M,t}) di \tag{1}$$

where profit π^i_m is the profit of the producer i in the production sector(denoted by subscript M that represents the respective technologies: u(unproductive technology), i(intermediate technology), p(productive technology)). S^i represents the amount of firm i shares that the individual worker owns. Q^i is the price for claiming a producer's future profits in the production sector. a_{t+1} denotes the worker's risk-free asset that has a return, r and W is the wage.

3.3 Production Sector

In the production sector, producers can borrow, B_{t+1}, and can issue Equity, Q_t. Issuing equity to raise capital requires that the firm pays a fraction of its future profits to its shareholders in future periods.

Borrowing is characterized with a collateral constraint shown below when M= u(unproductive producers), i(intermediate producers) or p(productive producers):

$$B_{t+1} \leq \theta(K_{t+1} + \kappa_M) \tag{2}$$

As κ_u=0, the unproductive producer only has capital as collateral. $\theta \in [0,1)$ is the parameter governing the collateral constraint, where a higher value denotes a loose constraint and allows for

[4]The expression, $a + \int S^i Q^i di$, which represents the worker's asset holdings, is non-negative to set that workers cannot borrow. Although when η_t is 0, it can be zero as one of the elements of the worker's efficiency, η_t, is 0, which also allows the natural borrowing limit(3) to be zero in some instances.

more borrowing.[5] The collateral constraint (2) states that borrowing is an increasing function of capital installed in the current period t, K_{t+1}, as well as the amount of intangible capital spent for its current technology, κ_M. The assumption here is that capital used for production in the next period is already installed in the current period. Furthermore, for computational simplicity, how much K_{t+1} to invest is assumed to be measurable with respect to $A_{e,t+1}$. This allows for the simple expression of the producer's profit as a function of its net worth, a = K - B. More importantly, to provide credibility to the producers borrowing from its lender, producers must withhold a minimum net worth, a_{min}, so that the producer is able to repay its debt even under the worst possible productivity shock, $A_{e,1}$. Hence the expression in (3), the natural borrowing constraint, might be more binding than the collateral constraint (2) in some circumstances.

$$a > a^M_{\min} = -\frac{(1-\theta\xi)\pi^M(a_{\min}, A_{e,1})}{r} \tag{3}$$

where π^M represents the profit of M=u(unproductive producers),i(intermediate producers), p(productive producers) in the production sector.[6] To understand how (3) and (2) work together to provide debt repayment credibility to the producers and that they will not consume all its borrowing and keep borrowing more from its lender, consider the event of the worst possible productivity shock, $A_{e,1}$, which enters $Y_{M,t}$ in the following expression $Y_{M,t} - WL_t - (1-\delta)K_t$ for operating income. Also, note that $(1+r)B_t$, debt to its lenders, is paid first before paying dividends to its shareholders. So if $(1+r)B_t$ is too high, it will restrict B_{t+1} from being higher so those producers will not keep borrowing, as the natural borrowing constraint will be more binding than the collateral constraint. This is because if the producer sets consumption to zero and even forgoes dividend payment to its shareholders, K_{t+1} will be negative from the budget constraint (7), and this prevents the producers from borrowing more based on the collateral constraint. Hence the producer must have the ability to pay back its debt to take more loans, which requires investment in its tangible and intangible capital based on the collateral constraint.

Next, production in the production sector requires two inputs: capital installed in the previous

[5] θ is less than 1, which on top of the explanation provided here help to avoid the issue of circulatory. This is because more borrowing spent on capital does not relax the collateral constraint by one-to-one but instead less than one.

[6] This expression is derived from the budget constraint (7) of the producer when consumption is set to zero, adding and subtracting $r(K_t)$ to the right-hand side of (7), and finally using the net worth formulation.

period(K_t) and labor.

$$Y_{M,t} = exp(A_e + A_M)^{1-\nu}((L_t)^{\alpha}(K_t)^{1-\alpha})^{\nu}$$

where α governs the proportion of labor share to production. A_M denotes the additional productivity producers in the production sector have over producers in the traditional sector. Depending on the level of technology the producers in the production sector subscribes to, A_M can represent A_u=0 or A_i or A_p productivity level such that $A_u = 0 < A_i < A_p$. With respect to these technologies, a higher level of technology is associated with a higher cost, i.e $\kappa_u = 0 < \kappa_i < \kappa_p$. Specifically, κ_p = $exp(A_p - A_i)\kappa_i$.

Unproductive or intermediate producers who want to upgrade to the productive technology face the same cost κ_p. Therefore, this creates the feature that even though the unproductive producer faces a lower cost of upgrading to the intermediate technology over the productive technology, intermediate producers that eventually decide on adopting the frontier technology will face the same cost as unproductive workers that adopt this frontier technology as well. Even though production sector producers who have upgraded to the intermediate technology will not see a reduction in the cost of adopting productive technology afterwards, the quantitative results of this paper show that intermediate technology can buffer the losses when the constraint parameter tightens. This provides some relevance for the addition of intermediate technology in this economy.

In terms of the collateral constraint, producers with different technology levels will face a different specification. However, production sector producers who adopted the productive technology directly from unproductive technology or indirectly by first upgrading to the intermediate technology level will observe the same collateral constraint specification.

3.3.1 Unproductive, Intermediate, and Productive Producers

Producers who first enter the economy will have an unproductive level of technology. Only in subsequent periods will producers in the production sector be able to attain a higher level of technology, A_i or A_p.

Budget constraint of producers that just entered the production sector and adopting unproductive technology, u:

$$C_t + K_{t+1} + \kappa_u = B_{t+1} + \xi \theta Q_t \tag{4}$$

where κ_u=0. Producers that just entered the production sector finances their consumption and expenditure on capital by raising funds from new borrowing and issuing equity[7]

A one-time issuance of equity takes place only when producers first enter the production sector where $\xi \in [0,1]$ is the parameter governing the equity issuance claim.

Budget constraint of producers in the production sector that are upgrading the technology to M = i or p:

$$C_t + K_{t+1} + \kappa_M = Y_{M,t} - WL_t + (1-\delta)K_t - (1+r)B_t + B_{t+1} - \xi \theta \pi_{M,t} \tag{5}$$

Producers that just upgraded their technology in the production sector finance their consumption and expenditure on tangible and intangible capital by raising funds from engaging in new borrowing and the internal funds the firm already has.

As mentioned, the cost of upgrading the technology level here also increases if the unproductive producers decide to adopt the higher frontier technology.

Profit of producers in the production sector with technology M= u, i, p[8]:

$$\pi_{M,t} = exp(A_e + A_M)^{1-\nu}((L_t)^{\alpha}(K_t)^{1-\alpha})^{\nu} - WL_t - (r+\delta)K_t \tag{6}$$

FOC:

(L_t)

$$W = exp(A_e + A_M)^{1-\nu}(\alpha\nu)l^{\alpha\nu-1}k^{(1-\alpha)\nu}$$

Factoring out l:

$$l = (\frac{\alpha\nu}{w})^{\frac{1}{1-\alpha\nu}} k^{\frac{(1-\alpha)\nu}{1-\alpha\nu}} exp(A_e + A_M)^{\frac{1-\nu}{1-\alpha\nu}}$$

(K_t)

[7] The one-time issuance of equity for new producers in the economy finances for the initial capital stock as these producers enter the economy with zero wealth.

[8] In the profit function, the is a r that signifies the interest to capital. In other words, it is the opportunity cost that the producer forgoes if the capital is used in production. The producer can rent its capital to other producers if it is not used in production.

$$(r+\delta) = exp(A_e + A_M)^{1-\nu} l^{\alpha\nu}(1-\alpha)\nu k^{(1-\alpha)\nu-1}$$

Factoring out k:

$$k = (\frac{\nu-\alpha\nu}{r+\delta})^{\frac{1}{1-(1-\alpha)\nu}} l^{\frac{\alpha\nu}{1-(1-\alpha)\nu}} exp(A_e + A_M)^{\frac{1-\nu}{1-(1-\alpha)\nu}}$$

Combining the two FOCs above, we derive the following two expressions:

$$l^m(a_{i,t}, A_{e,t}) = \left(\frac{\alpha\nu}{W}\right)^{\frac{1-(1-\alpha)\nu}{1-\nu}} \left(\frac{\nu-\alpha\nu}{\tilde{r}_{it}+\delta}\right)^{\frac{(1-\alpha)\nu}{1-\nu}} \exp(A_e + A_M)$$

$$k^m(a_{i,t}, A_{e,t}) = \left(\frac{\alpha\nu}{W}\right)^{\frac{\alpha\nu}{1-\nu}} \left(\frac{\nu-\alpha\nu}{\tilde{r}_{it}+\delta}\right)^{\frac{1-\alpha\nu}{1-\nu}} \exp(A_e + A_M)$$

Where the shadow cost of funds is

$$\tilde{r}_{it} = \begin{cases} r \text{ if } \left(\frac{\alpha\nu}{W}\right)^{\frac{\alpha\nu}{1-\nu}} \left(\frac{\nu-\alpha\nu}{\tilde{r}_{it}+\delta}\right)^{\frac{1-\alpha\nu}{1-\nu}} \exp(A_e + A_M) < \frac{1}{1-\theta}(a_t + \theta\kappa_M) \\ \left(\frac{\alpha\nu}{W}\right)^{\frac{\alpha\nu}{1-\alpha\nu}} (\nu-\alpha\nu) \left(\frac{\exp(A_e+A_M)}{\frac{1}{1-\theta}(a_t+\theta\kappa_M)}\right)^{\frac{1-\nu}{1-\alpha\nu}} - \delta \text{ otherwise} \end{cases}$$

The first row is when the collateral constraint does not bind. The second row above is with a binding collateral constraint, in other words, when (2) is set to equals.[9]

Hence, we can derive an explicit form of the output in the production sector.

$$y_{it} = \left(\frac{\alpha\nu}{W}\right)^{\frac{\alpha\nu}{1-\nu}} \left(\frac{\nu-\alpha\nu}{(\tilde{r}_{it}+\delta)}\right)^{\frac{(1-\alpha)\nu}{1-\nu}} \exp(A_e + A_M)$$

Consequently, this implies that the producer in the production sector has the following profit.

$$\pi_{M,t} = (1-\nu)\left(\frac{\alpha\nu}{W}\right)^{\frac{\alpha\nu}{1-\nu}} \left(\frac{\nu-\alpha\nu}{(\tilde{r}_{it}+\delta)}\right)^{\frac{(1-\alpha)\nu}{1-\nu}} \exp(A_e + A_M)$$

[9]The expression in the second row is derived from plugging in the expression for k^m that contains $\tilde{r}_{it}$ into the new expression for the collateral constraint shown in the bellman equation section of the paper while setting it to equals.

Lastly, the budget constraint of a producer with a current state of technology M= u or i or p is

$$C_t + K_{t+1} = Y_{M,t} - WL_t - (1+r)B_t + B_{t+1} + (1-\delta)K_t - \xi\theta\pi_{M,t} \tag{7}$$

The budget constraint (6) implies that consumption and investment are funded by the firm's internal funds and new borrowing but after repaying for the one-period loan and paying its stockholders.

3.4 Bellman form along a balanced growth path

Here, a small caps notation for the variables, apart from productivity, discussed in the previous sections and a simpler notation where the net worth of a producer is such that: a = $k_{t+1} - b_{t+1}$ is utilized. This net worth notation is similar to the one used in Midrigan and Xu (2014), which is also helpful for computational purposes.

Note that the net worth of producers in this economy, intermediate and productive producers specifically, can be negative. [10] Also, because debt is uncontingent in the model, there is a natural borrowing constraint that could be more binding for the producers than the collateral constraint. The natural borrowing constraint requires the producer to possess a minimum net worth that can repay its debt under the worst-possible sequence of transitory productivity shocks.

Having defined the scaled notation of net worth, a, then constant factor prices together with the transitory productivity A_e provides us with the decision rule for the three types of producers in this economy.

Firstly, the value of a producer who just entered the production sector and has unproductive technology is expressed as

$$V^u(a, A_{e,i}) = \max_c \log(c) + \beta \max \left\{ \begin{array}{c} \sum_j f_{i,j} V^u\left(a', A_{e,j}\right), \\ \left(\sum_j f_{i,j} V^i\left(a' - \kappa_i, A_{e,j}\right)\right) \mathrm{I}_{a' > \kappa_i + \underline{a}_i}, \\ \left(\sum_j f_{i,j} V^p\left(a' - \kappa_p, A_{e,j}\right)\right) \mathrm{I}_{a' > \kappa_p + \underline{a}_p} \end{array} \right\} \tag{8}$$

subject to

[10]Because producers can utilize their intangible capital as collateral to borrow, it provides to intuition for the quantitative results that follow showing a that they can have a negative net worth.

$$\begin{aligned} &\text{Producers just entering} \qquad c + a' + \kappa_u = \theta\chi q^u\left(a', A_{e,j}\right) \\ &\text{Unproductive producers} \qquad c + a' = (1-\theta\chi)\pi^u(a, A_e) + (1+r)a \end{aligned} \tag{9}$$

where $q^u(a', e)$ is the price to claim an entire stream of the producer's future profit. The subscript u is to signify that producers who first enter the production sector can only pick up the unproductive technology. The expression below, also known as the no-arbitrage condition, shows the mathematical form of this price variable.

$$q\left(a, A_{e,i}\right) = \frac{1}{1+r}\sum_j f_{i,j}\left[q\left(a', A_{e,j}\right) + \pi^m\left(a', A_{e,j}\right)\right] \tag{10}$$

and faces the collateral constraint, where κ_u=0

$$k \leq \frac{1}{1-\theta}a + \frac{\theta}{1-\theta}\left(\kappa_u\right) = \frac{1}{1-\theta}a \tag{11}$$

Secondly, the value of a producer with intermediate technology in the production sector is expressed as

$$V^i(a, A_{e,i}) = \max_c \log(c) + \beta \max\left\{ \begin{array}{c} \sum_j f_{i,A_{e,j}} V^i\left(a', A_{e,j}\right), \\ \left(\sum_j f_{i,j} V^p\left(a' - \kappa_p, A_{e,j}\right)\right) \mathrm{I}_{a' > \kappa_p + \underline{a}_p} \end{array} \right\} \tag{12}$$

subject to

$$c + a' = (1-\theta\chi)\pi^i(a, A_e) + (1+r)a \tag{13}$$

and the collateral constraint

$$k \leq \frac{1}{1-\theta}a + \frac{\theta}{1-\theta}\left(\kappa_i\right) \tag{14}$$

Lastly, the value of a producer who has adopted productive technology in the production sector is expressed as

$$V^p(a, A_{e,i}) = \max_c \log(c) + \beta\sum_j f_{i,j} V^p\left(a', A_{e,j}\right) \tag{15}$$

subject to

$$a' = (1-\theta\chi)\pi^p(a, A_e) + (1+r)a - c \tag{16}$$

and the collateral constraint

$$k \leq \frac{1}{1-\theta}a + \frac{\theta}{1-\theta}(\kappa_p) \tag{17}$$

3.5 Definition of Balanced Growth Equilibrium

Let the notation $n_t^M(a,e)$ represent the measure of producers. Then the number of producers in the production sector add up to $N_t = \psi^t$ and is expressed as follows

$$\sum_{M=u,i,p} \int_{A\times E} dn_t^M(a,e) = N_t \tag{18}$$

Timing of producers: There is a measure N_t of producers in the economy. At the end of every period, $(\psi-1)N_t$ of producers enter the production sector as producers with unproductive technology that has no cost, κ_u=0. These entrants, at the start of the period, draw from a stationary distribution $\bar{f}_i$ their transitory productivity component A_e that evolves over time. As new producers have zero wealth, they will engage in a one-time issuance of equity, which gives claims to their future profit to finance their initial capital stock. For these new producers, only capital stock enters their collateral constraint, which allows them to borrow a fraction that is less than their capital stock. Hence, issuance of equity upon entry and engaging in borrowing finance the producer's consumption, capital stock, and intangible asset κ_M if the producer decides to upgrade his technology for the next period. If the producer has a higher level of technology, intermediate or productive, then it can utilize both K_{t+1} and κ_M as collateral for its borrowing. Producers that stay with the unproductive technology will only have their capital stock as collateral. Hence, after the first period that producers enter the economy, internal funds(particularly from its production) and new borrowing help raise funds needed for the firm's expenditure. These provide the finances for consumption, expenditure on labor, capital for the next period's production, repaying its one-period loan, dividend payments to its stockholders, and intangible asset if the producer decides to upgrade his technology for the next period.

Definition of Balanced Growth Equilibrium

A balanced growth equilibrium is a set of prices (wages(W), interest rate(r), and stock price(q(a,A_e))), policy functions for workers ($c_t^w(a,\eta)$ and $a_{t+1}^w(a,\eta)$), policy functions for producers ($c_t^k(a,A_e)$, and $a_{t+1}^k(a,A_e)$) where $k \in$ (unproductive(u), unproductive switching to intermediate(si), intermediate(i), intermediate switching to productive(spi), unproductive switching to productive(sp),productive(p)), switching decisions for producers in the production sector, measures of producers in the production sector ($n_{t+1}^{M}(a,A_e)$), as well as output, labor and capital decisions by the producers ($y^M(a,A_e)$, $l^M(a,A_e)$, $k^M(a,A_e)$) and they all satisfy

(i) the laws of motion for the measures of producers in the production sector

$$n_{t+1}^{M}\left(A,A_{e,j}\right)=\sum_{M=u,i,p}\int_{A}\sum_{i}f_{i,j}\mathbf{I}_{\left\{a^M\left(a,A_{e,i}\right)\in A\right\}}dn_t^M\left(a,A_{e,i}\right)$$
$$+(\gamma-1)N_t\mathbf{I}_{\{0\in A\}}\bar{f}_j$$

where the compact set containing the values that the producerâs net worth can take is $A=[\underline{a},\bar{a}]$, and let A denote a family of its subsets. $\mathbf{I}_{\left\{a^M\left(a,A_{e,i}\right)\in A\right\}}$ represents producers that entered the economy in the previous period while $\mathbf{I}_{\{0\in A\}}$ signifies the new entering producers this period. $a^M(.)$ denotes the savings decision of a producer in the production sector. Again, note that $a^M(.)$=0 for an entering producer as a producer that first enters the production sector has zero wealth. Also, $\bar{f}_j$ is the stationary distribution of the transitory productivity.

(ii) producer and worker optimization as described in the earlier portion of this section.

(iii) the no-arbitrage condition

$$q\left(a,A_e\right)=\frac{1}{1+r}\sum_{j}f_{i,j}\left[q\left(a_{t+1},A_{e,j}\right)+\pi^M\left(a_{t+1},A_{e,j}\right)\right]$$

(iv) the labor market clearing condition

$$L_t=\sum_{M=u,i,p}\int_{A\times E}l^M(a,A_e)dn_t^M(a,A_e)$$

where $L_t=\psi^t$ is the total amount of efficiency units of labor supplied by the workers[11]

(v) and the asset market clearing condition

$$A_{t+1}^{w}+\sum_{M=u,i,p}\int_{A\times E}\sum a_{t+1}^{M}(a,A_e)dn_{t+1}^{M}(a,A_e)=\sum_{M=u,i,p}\int_{A\times E}k_{t+1}^{M}(a,A_e)dn_{t+1}^{M}(a,A_e)$$

[11]It is not necessary to include the η term in the labor market clearing condition as its mean can be normalized to unity and so is left out for simplicity.

Lastly, note that the consumer decision rules and the measures of producers are variables denoted with a time subscript because they grow at a constant rate ψ along a balanced growth path. Thus, to solve for the balanced growth equilibrium, these variables are rescaled by ψ^t before solving for the resulting stationary system, as in Midrigan and Xu (2014). All other variables like the producer decision rules and the equity pricing functions are not rescaled as they are time-invariant.

3.6 Calibration

The model is calibrated to micro-level data related to firms in the Chilean manufacturing industry. From the motivation section of this paper, Chile is an economy where firms possess an intermediate level of TFP and relate to an intermediate technology level. Separate calibrations are also performed for the micro-level data set for the US economy with the highest mean firm TFP and the Egypt economy with the lowest mean firm TFP. Further details on the derivation of the micro-level data set for the economies in this paper can be found in the Appendix. Specifically for the micro-level data set for Chile's firm, it was obtained from the INE, and they provide coverage from 1997 to 2015. Also, note that each time interval for this paper is one year.

Table 4 lists the parameters with values assigned based on what is standard in the literature. Firstly, ψ is set to match the real annual growth rate of the Chilean manufacturing sector value-added. The discount rate β follows from Buera, Kaboski, and Shin (2011) and Midrigan and Xu (2014), which takes on a value with relatively impatient agents.[12] The values for elasticity of labor in production α, span of control parameter ν, and capital depreciation rate δ all follow stand values in related literature. The worker's efficiency follows a two-state Markov process with $\lambda_i \in \{0,1\}$. In order to have a match to Chile's employment data, the probability of staying unemployed (state=0) is $\lambda_0 = 0.5$ and the probability of staying employed (state=1) is $\lambda_1 = 0.54$. Setting these probabilities ensures that 52% of Chile's population supplies labor in each period.

[12] Similar to Midrigan and Xu (2014), as the consumption variable grows at a rate of ψ, due to being in a balanced growth equilibrium, and together with the logarithmic utility function, these imply that the discount factor is based on the following expression: $\beta/\psi = 0.92$.

Assigned Parameters	Economy with Intermediate Technology(Model)	Source
ψ growth rate	1.025	Output in Chile manufacturing grew at an annual real rate of 2.5 %
β, discount factor	0.92*ψ	Following Buera, Kaboski, and Shin (2011) and Midrigan and Xu (2014)
α, elasticity of labor in production	2/3	Standard value in the literature
ν, span-of-control parameter	0.85	Following Basu and Fernald (1997) and Atkeson and Kehoe (2007)
δ, capital depreciation rate	0.06	Standard value in the literature
λ_1, Persistence unit worker state	0.54	To match with Chile's employment to population ratio of 52%
λ_0, Persistence zero worker state	0.5	To match with Chile's employment to population ratio of 52%
κ_u, Cost of entering production sector with unproductive technology	0	Setting zero cost for unproductive technology

Table 4: Calibration: Assigned Parameters for Chile Data

This worker efficiency process characterizes the precautionary savings motive, which drives the equilibrium interest rate for the economy.[13] Finally, as producers enter the economy with no wealth, the cost to adopt an unproductive technology is set to zero.

3.6.1 Calibration: Chile Data

Calibration of the model in this paper is performed with the Chile micro-level data set obtained from National Statistics Institute (INE). The Annual National Industrial Survey (ENIA) data set from the INE provides information on the manufacturing industry, and it collates data in an annual frequency. From this ENIA data set, relevant data such as the firm's production, sales, income, purchase of inputs and raw materials, employment, and remuneration were used from 1996 to 2015.

Table 5 provides the data moments targeted for the corresponding moments in the model to

[13] In order to determine the equilibrium interest rate for the Benchmark economy, it is first assumed that the economy is closed to pin down the equilibrium interest rate from the asset market clearing condition. Then to derive the results in the quantitative section, the interest rate of the open economy stays the same as the benchmark economy while parameters like θ vary. The equilibrium interest rate derived is within the range of 4â5 percent, similar to the economies studied by Buera, Kaboski, and Shin (2011) and Midrigan and Xu (2014).

match. With regards to the different levels of technologies A_u,A_i, and A_p, their values are derived based on the log difference of mean TFPs to represent the additional productivity that producers will obtain from upgrading their technology.[14]

Targeted Moments for Calibration	Chile Data	Economy with Intermediate Technology (Model)
Proportion that moves from Intermediate to Productive Technology within 1 year	0.07	0.01
Proportion that moves from Unproductive to Intermediate Technology within 1 year	0.19	0.11
Proportion that moves from Unproductive to Productive Technology within 1 year	0.01	0.00
top 10% Labor Share	0.69	0.71
top 33.3% Labor Share	0.89	0.98

Table 5: Calibration: Targeted Moments for Chile Data

Targeted Moments for Calibration	Chile Data	Economy with Intermediate Technology (Model)
Log difference between the mean TFP of all producers in the US(Productive) and mean TFP for all producers in Egypt(Unproductive)	log(1.79)	log(1.79)
Log difference between the mean TFP of all producers in the Chile(Intermediate) and mean TFP for all producers in Egypt(Unproductive)	log(1.48)	log(1.48)
Standard deviation of output growth	0.74	0.74
Output growth rate in percentage	2.5 %	2.5 %
1-year autocorrelation of output	0.91	0.82
3-year autocorrelation of output	0.88	0.77
5-year autocorrelation of output	0.88	0.75
Intangibles invest. to output in percentage	1.8%	2.5%
Debt to output	1.06	1.03
Equity to output	0.92	1.07

Table 5: Calibration: Targeted Moments for Chile Data Continued

Table 6 reports the values for parameters derived from the model calibration to match the moments listed in table 5 closely. Data on value-added is utilized over final output as this paper's model draws away from intermediate inputs. Regarding the cost of adopting technology, κ_i and κ_p

[14]Values for A_u,A_i,A_p are taken in relation to relative mean TFP of the USA,Chile,and Egypt firms. For example, the mean TFP of the US firms over the mean TFP of Egypt firms is 1.79, which is used to formulate A_p

reflect the cost of intangible assets in the economy. Consequently, the values for these κ parameters are set to be close to the fixed capital formation to value-added ratio of 1.8 percent reported by Banco central Chile. The θ parameter that ties to the amount of debt producers can issue is calibrated so that model matches the debt-to-output ratio of 1.06 reported by BIS through its Credit to GDP Ratio for Chile.

Calibrated Parameters, Description	Economy with Intermediate Technology(Model)
κ_i, Cost of unproductive producers adopting intermediate technology in the production sector	1.4123
κ_p, Cost of unproductive or intermediate producers adopting productive technology in the production sector	5.0181
θ, Collateral constraint parameter	0.4344
ξ Equity issuance parameter	0.3155
ρ , Implied persistence of the transitory shocks	0.2168
σ_e, Standard Deviation of transitory shocks	0.8806

Table 6: Calibration: Calibrated Parameters

As for the ξ parameter associated with the one-time equity issuance by producers is calibrated to match the 0.92 equity to GDP ratio based on the World Bank data by Beck, DemirgüÃ§-Kunt, and Levine (2000). With regards to the transitory productivity shock, its volatility σ_e, and persistence component ρ is calibrated to match the standard deviation of output growth rates of 0.74, and the auto-correlation of the output of horizons of one: 0.91, three years: 0.88, and five years: 0.88.[15]

In the subsequent sections, it can be seen that the model does an excellent job in producing quantitative results that relate to the TFP patterns of different economies that are shown in figure 2. Specifically, only the Chilean economy has most of its producers choosing to adopt the intermediate technology that possesses this intermediate TFP level, which goes hand in hand with the data observation of most firms in Chile possessing an intermediate level of TFP. Wheres in the data for the US and Egypt, this intermediate level of TFP is certainly not the majority share of firms.

[15]The process for the transitory productivity A_e is assumed to evolve according to an AR(1) process with Gaussian disturbances. Similar to Midrigan and Xu (2014), the process is discretized using the Rouwenhorst method.

3.7 Quantitative results

3.7.1 Chile: Small Open Economy where unproductive producer can upgrade to affordable intermediate technology or expensive productive technology

Having performed the necessary calibration for the model, this section discusses the aggregate effects of financial frictions. From the calibration, the respective costs of upgrading to the intermediate and frontier technology are κ_i=1.4123 and κ_p=5.0181. Clearly, adopting the technology at the frontier is much more expensive than intermediate technology.

Table 7 expresses the results of an economy where unproductive producers who cannot afford the frontier technology can go to an intermediate technology that is cheaper. Here, the quantitative results show that the economy's growth is mainly due to technological upgrading by the producers. With Chile having a moderately developed financial market, most producers have an intermediate technology. In the benchmark economy for Chile, where θ=0.43, the share of producers are predominately having the intermediate level of technology. As shown in table 7, 0.477 of the producers possess intermediate technology, followed by 0.321 of producers with productive technology and a minor fraction of 0.202 having the entry level technology. In the benchmark economy, not all producers end up with productive technology as agents are fairly impatient, with a low discount factor of β/γ=0.92.

Variables of Interest	Benchmark Economy θ= 0.43	θ= 0.75	θ= 0.50	θ=0.25
Consumption	2.131	2.172	2.170	1.997
Output	2.650	2.854	2.729	2.379
TFP	1.630	1.657	1.639	1.517
Fraction productive producers	0.315	0.393	0.325	0.209
Fraction intermediate producers	0.432	0.102	0.413	0.263
Fraction unproductive producers	0.253	0.505	0.262	0.528

Table 7: Effects of Financial Friction on the Technological Adoption Channel when there is an intermediate productive producer

To derive the quantitative results of the collateral constraint, only the θ variable is allowed to vary while the other calibrated parameters in table 6 remain the same as in the benchmark case. Additionally, as the economy is a small open economy, the interest rate remains fixed while θ varies. As $\theta \xi q(a, A_e)$ is the amount of equity issued by the producers, reducing θ implies tightening of the collateral constraint and that less equity is being issued.

When θ decreases, in other words, the collateral constraint tightens, TFP in the production sector drops from 1.657 to 1.517. The initial drop of θ from 0.75 to 0.5 only results in a slight drop, while most of the drop occurs when θ drops from 0.5 to 0.25. Similarly, this is also the case for aggregate variables such as consumption and output. Specifically, when θ drops from 0.75 to 0.25, aggregate consumption drops by around 8 percent while aggregate output drops by around 18 percent, where the majority of the drop occurs from θ declining from 0.5 to 0.25. This quantitative result on the aggregate variables can be associated with the share of producers in the production sector. When θ drops from 0.75 to 0.5, the fraction of productive producers declines moderately while intermediate technology producers in fact, increase.

This is because when θ=0.75, the natural borrowing constraint influences the technological upgrading decision of producers in the production sector based on the equation shown in (3).

When θ=0.75, the economy is in a situation where the natural borrowing constraint dominates the collateral constraint. This natural borrowing limit enforces producers to accumulate sufficient net worth to repay their debt should a disastrous productivity shock arise. Fewer producers will decide to upgrade their production technology until it accumulates enough savings to maintain a level of net worth above the borrowing limit. Thus, in table 8, with a setting of θ=0.75, a larger than expected proportion of the producers stay with its unproductive technology. Hence, this natural borrowing constraint that is dominant when θ is 0.75 explains the high proportion of producers staying with its unproductive technology. Thus, even when θ is high, many producers stay as intermediate producers, which causes aggregate variables not to differ as much as when θ=0.5 where the natural borrowing constraint is less binding.

In table 8, $a^u_{\min}$ is zero and not negative as unproductive producers do not pay the cost for that technology and hence are not able to collateralize any intangible asset. Obviously, for the case of when θ declines from 0.5 to 0.25, a tighter collateral constraint and a tighter natural borrowing constraint leads to a small proportion of producers that will upgrade their technology and a corresponding decline in aggregate variables.

$a^M_{\min}$	Benchmark(θ= 0.43)	θ= 0.75	θ= 0.50	θ=0.25
Productive technology producers, $a^p_{\min}$	-1.53	-1.05	-1.37	-1.09
Intermediate technology producers, $a^i_{\min}$	-0.43	-0.30	-0.39	-0.31
Unproductive technology producers, $a^u_{\min}$	0.00	0.00	0.00	0.00

Table 8: Minimum net worth to avoid the natural borrowing constraint in Economy with Intermediate Technology

Hence, financial friction through the channel of restricting producers from having sufficient capital to upgrade their technology has a sizable impact on aggregate variables in the economy.

3.7.2 Chile: No intermediate technology in SOE

In this section 3.7.2, quantitative results of two different technological settings for the Chilean economy shown in table 7 and 9 are being compared. Table 9 showcases the results in an economy where producers in the production sector can only upgrade to the frontier technology that might require some producers to save sufficient capital in order to do so.

Comparing the two economies brings forward several results. For one, the economy with intermediate technology exhibit higher levels in terms of its aggregate variables for the different θ levels. This implies that for an economy with a moderately developed financial market, Chile will benefit from including an additional intermediate level of technology.

Variables of Interest	θ= 0.75	θ= 0.50	θ=0.25
Consumption	1.832	1.840	1.740
Output	2.363	2.241	2.040
TFP	1.477	1.422	1.372
Fraction productive producers	0.189	0.174	0.144
Fraction unproductive producers	0.811	0.826	0.856

Table 9: Effects of Financial Friction on the Technological Adoption Channel without an intermediate producer in the production sector

In terms of the decline of aggregate variables when θ declines, the economy with an intermediate technology exhibits a similar pattern where the majority of the decline happens when θ

drops from 0.5 to 0.25. Overall, the decline in the aggregates is relatively smaller in an economy without intermediate technology. This reflects the result that if Chile is allowed to rely more on intermediate technology, its economy's development will be more severely affected when the collateral constrain tightens as the intermediate technology will be a relevant technology for most of its producers.

$a^M_{\min}$	θ= 0.75	θ= 0.50	θ=0.25
Productive technology producers, $a^p_{\min}$	-2.12	-2.09	-1.14
Unproductive technology producers, $a^u_{\min}$	0.00	0.00	0.00

Table 10: Minimum net worth to avoid the natural borrowing constraint in Economy without Intermediate Technology

With regards to the share of producers, in an economy with intermediate technology, the minimum net worth of productive producers, as shown in table 10, is the highest when θ =0.75. This corresponds to table 9, reflecting that the fraction of productive producers declines and the fraction of unproductive producers increases as θ declines. This pattern was not necessarily apparent in the case of the economy with an intermediate technology.

3.7.3 The US: Large Open Economy with Intermediate Technology

For the quantitative results of the US economy shown in table 11, the interest rate is allowed to vary with the θ values. Allowing interest rates to vary is to accommodate the fact that the US is a large open economy.

For the US economy, several findings emerge. Being an economy with a well-developed financial market, the benchmark economy exhibits that most producers adopt the productive technology. Hence, the composition of producers is strikingly different from Chile's benchmark economy. This comparison of the composition of producers in economies with different financial development supports the claim that a more well-developed economy has a higher proportion of producers with frontier technology. In terms of aggregate variables, the benchmark economy for the US has clearly higher levels than the one in Chile. With a more significant number of producers adopting the frontier technology, the quantitative results point to the benchmark economy for the US having a higher aggregate consumption, output, and TFP.

Variables of Interest	Benchmark Economy θ= 0.7147	θ= 0.75	θ= 0.50	θ=0.25
Consumption	2.343	2.439	2.295	2.169
Output	2.886	2.946	2.809	2.609
TFP	1.803	1.782	1.748	1.671
Interest rate	0.0640	0.0650	0.0530	0.0393
Fraction productive producers	0.616	0.605	0.471	0.339
Fraction intermediate producers	0.177	0.00	0.488	0.622
Fraction unproductive producers	0.207	0.395	0.041	0.039

Table 11: Effects of Financial Friction on the Technological Adoption Channel when there is an intermediate productive producer in the production sector

In a large open economy such as the US, it would be interesting to look into the effects of the interest rate variable, which was not of interest for a small open economy like Chile. Interest rates decline across the different θ levels when the collateral constraint tightens. When θ decreases, producers cannot borrow as much capital, which implies a decline in interest rates as overall borrowing in the economy falls.

Additionally, when θ decreases, the proportion of productive producers declines while intermediate technology producers increase. As the collateral constraint tightens, producers that could adopt the frontier technology when θ was 0.75 will switch to the intermediate technology at lower θ levels. As for the aggregate TFP, it drops from 1.782 to 1.671. For the other aggregate variables like consumption and output, they both drop by around 11 percent, whereas the decline of θ from 0.5 to 0.25 constitutes slightly more of a drop.

Therefore, with a well-developed financial market such as the one in the US economy, intermediate technology seems to play a minor role, as seen for the low proportion in the benchmark economy. Nevertheless, when the economy faces a bad time, an intermediate technology could help reduce the impact of financial frictions on the aggregate TFP and output as we see more producers upgrading to this alternative technology when θ is low. The share of intermediate producers in the US economy would continue to increase as the collateral constraint tightens, unlike Chile's small open economy. Hence, the drop in aggregate TFP and output from θ=0.75 to 0.25 is more diminutive than Chile's economy in section 3.7.1.

3.7.4 Egypt: Small Open Economy with Intermediate Technology

Similar to the quantitative methodology performed on the Chilean economy, the quantitative results for Egypt's economy are obtained by only varying the θ variable while keeping the other calibrated parameters the same as in the benchmark case for Egypt. Likewise, the interest rate remains fixed while θ varies.

Variables of Interest	Benchmark Economy θ= 0.313	θ= 0.75	θ= 0.50	θ=0.25
Consumption	1.750	2.001	1.883	1.729
Output	2.336	2.828	2.567	2.298
TFP	1.500	1.626	1.565	1.484
Fraction productive producers	0.196	0.283	0.255	0.182
Fraction intermediate producers	0.235	0.285	0.270	0.234
Fraction unproductive producers	0.569	0.432	0.475	0.583

Table 12: Effects of Financial Friction on the Technological Adoption Channel when there is an intermediate productive producer in the production sector

From table 12, it can be observed that aggregate TFP, consumption, and output all drop when θ decreases. When the collateral constraint tightens, aggregate TFP, consumption, and output in the production sector drop by around 18.7, 13.6, and 8.73 percent, respectively. The rationale for the quantitative decline in aggregate variables can be associated with the change in producers' share in the production sector. When θ drops from 0.75 to 0.25, table 12 shows that the fraction of productive producers and intermediate producers in the economy continues to decline while the share of produces with entry-level technology becomes higher. Thus, financial friction through the technological adoption channel has a sizable impact on aggregate variables in this economy.

Overall, a cross-country comparison reveals that intermediate technology benefits the economy's aggregate variables. Although Egypt's aggregate TFP, consumption, and output are lower than those in Chile, they are higher for almost all cases compared to a more financially developed Chile economy with no intermediate technology.

3.8 Extension: Misallocation

Similar to papers in the misallocation literature, Hsieh and Klenow (2009), Buera, Kaboski, and Shin (2011), and Midrigan and Xu (2014), the extension section here investigates TFP losses due to misallocation. Here, the methodology prescribed is adapted from Midrigan and Xu (2014). Hsieh and Klenow (2009) report that misallocation account for half of the TFP gap to the US for countries like China or India, while Buera, Kaboski, and Shin (2011) report around a one-third drop in TFP. On the other hand, Midrigan and Xu (2014) point to a substantially smaller drop in TFP due to misallocation. Hence, this section aims to measure the level of disruption to TFP due to misallocation when an intermediate technology is introduced to the economy. Specifically, looking into how financial frictions prevent capital allocation to productive producers, thereby causing misallocation losses in terms of TFP levels.

First, denote i for a producer in the production sector(M). Then let L and K signify the aggregate amount of labor and capital utilized in the production sector. Also, utilization of this paper's measurable assumption on capital implies that profit is a function of net worth and not capital or debt. With this simplification and using the notation used in the bellman equation of the balanced growth equilibrium section, the profit of producers can be expressed as follows

$$\pi(a,A_e) = max\ exp(A_e + A_M)^{1-\nu}(l^{\alpha}k^{1-\alpha})^{\nu} - Wl - (r+\delta)k$$

subsequently, the FOCs with the collateral constraint $k \leq \frac{1}{1-\theta}a + \frac{\theta}{1-\theta}(\kappa_M)$ that has a multiplier $\mu(a,A_e)$ are expressed as

$$W = \alpha\nu\frac{y(a,A_e)}{l(a,A_e)}$$

$$r+\delta = \nu(1-\alpha)\frac{y(a,A_e)}{k(a,A_e)} - \mu(a,A_e)$$

which correspondingly gives the below two expressions for the allocations

$$L_i = \frac{\exp\left(A_e^i + A_M^i\right)(r+\delta+\mu_i)^{-\frac{(1-\alpha)\nu}{1-\nu}}}{\int_{i\in M}\exp\left(A_e^i + A_M^i\right)(r+\delta+\mu_i)^{-\frac{(1-\alpha)\nu}{1-\nu}}}L$$

$$K_i = \frac{\exp\left(A_e^i + A_M^i\right)(r+\delta+\mu_i)^{\frac{\alpha\nu-1}{1-\nu}}}{\int_{i\in M}\exp\left(A_e^i + A_M^i\right)(r+\delta+\mu_i)^{\frac{\alpha\nu-1}{1-\nu}}} K$$

Then integrating across producers for the two decision rules above together with the multiplying of the aggregate labor to the power of $\alpha\nu$ and aggregate capital to the power of $(1-\alpha)\nu$ will result in the following expression for the total amount of output produced by all the producers in the economy

$$Y = \underbrace{\frac{\left(\int_{i\in M}\exp\left(A_e^i + A_M^i\right)(r+\delta+\mu_i)^{-\frac{(1-\alpha)\nu}{1-\nu}}\, di\right)^{1-\alpha\nu}}{\left(\int_{i\in M}\exp\left(A_e^i + A_M^i\right)(r+\delta+\mu_i)^{\frac{\alpha\nu-1}{1-\nu}}\, di\right)^{(1-\alpha)\nu}}}_{=TFP} \left(L^{\alpha}K^{1-\alpha}\right)^{\nu} \tag{19}$$

The terms underlined as TFP represent the TFP of the production sector. It reflects the endogenous component that incorporates the terms relating to the measure of producers operating, their efficiency, and how constrained they are.

Having computed the TFP level in the production sector, the next task would be to calculate the efficient level of TFP taking as given the same set M of producers. The setting here is simply the planner's problem where capital and labor are allocated across the given set of producers to maximize the total output produced in the economy. The planner is subject to the same amount of aggregate labor and capital as the initial economy without a planner allocating the resources.

The planner's problem is such that it solves

$$\max_{K_i, L_i} \int_{i\in M} \exp\left(A_e^i + A_M^i\right)^{1-\nu} \left(L_i^{\alpha} K_i^{1-\alpha}\right)^{\nu} di \tag{20}$$

subject to

$$K = \int_{i\in M} K_i di, \quad L = \int_{i\in M} L_i di$$

Equalizing the marginal product of capital and labor of the producers in the economy will lead to the solution for this planner's problem. Solving the planner's problem results in the following formulation for the efficient level of output

$$Y^e = \underbrace{\left(\int_{i\in M} \exp\left(A_e^i + A_M^i\right) di\right)^{1-\nu}}_{=TFP^{Efficient}} \left(L^\alpha K^{1-\alpha}\right)^\nu \tag{21}$$

Specifically, factoring out the efficient TFP level gives

$$TFP^{Efficient} = \frac{Y^e}{\left(L^\alpha K^{1-\alpha}\right)^\nu} = \left(\int_{i\in M} \exp\left(A_e^i + A_M^i\right) di\right)^{1-\nu}$$

Hence, taking the difference between $TFP^{Efficient}$ and TFP, and using the earlier expression that $r + \delta + \mu(a, A_e) = \nu(1-\alpha)\frac{y(a,A_e)}{k(a,A_e)}$ gives

$$\begin{aligned}\text{TFP Loss} = &\log\left(\int_{i\in M} \exp\left(A_e^i + A_M^i\right) di\right)^{1-\nu} \\ &- \log \frac{\left(\int_{i\in M} \exp\left(A_e^i + A_M^i\right)\left(\frac{y_i}{k_i}\right)^{-\frac{(1-\alpha)\nu}{1-\nu}} di\right)^{1-\alpha\nu}}{\left(\int_{i\in M} \exp\left(A_e^i + A_M^i\right)\left(\frac{y_i}{k_i}\right)^{\frac{\alpha\nu-1}{1-\nu}} di\right)^{(1-\alpha)\nu}}\end{aligned}$$

Therefore, the above expression provides a computational method to illustrate the misallocation losses in TFP in the next section.[16]

3.8.1 Misallocation : quantitative result

Here, tables 13 and 14 provide the quantitative result comparison of misallocation losses between the economy with an intermediate technology and without an intermediate technology, respectively.

[16]To gain some intuitive understanding of the expression of TFP loss, Midrigan and Xu (2014) assume that the logarithm of y_i/k_i and A_e are jointly normally distributed. This assumption provides an intuitive form where TFP loss $= \frac{1}{2}\frac{(1-\alpha\nu)(1-\alpha)\nu}{1-\nu}\operatorname{var}(\log(y_i/k_i))$. If no other sources to the variation of the average product of capital are present, then TFP losses are proportionally related to the variance of the average product of capital. Because equalization of the marginal product of capital is required to derive the efficient allocations, any disparity in the average product of capital will cause TFP losses based on their derived expression.

Variables of Interest	Benchmark θ= 0.43	θ= 0.75	θ= 0.50	θ=0.25
Loss misallocation, percent	3.1%	1.2%	2.8%	4.2%

Table 13: Effects of Financial Friction on the Technological Adoption Channel when there is an intermediate productive producer in the sector

Variables of Interest	θ= 0.75	θ= 0.50	θ=0.25
Loss misallocation, percent	1.2%	4.0%	5.0%

Table 14: Effects of Financial Friction on the Technological Adoption Channel without an intermediate producer in the sector

When an intermediate technology is introduced to the economy, the losses from misallocation are lower or the same for all cases of θ. This implies that having a more variety menu of technology allows for capital to be allocated more efficiently and reduces the losses from misallocation in terms of TFP levels.

In sum, the result is that losses through the misallocation channel do not exacerbate and stay relatively small when an intermediate technology is introduced, further emphasizing that most of the economy's losses occur through the technological channel. For this reason, most of the quantitative analysis of this paper is focused on the aggregate losses through the technological adoption channel.

4 Conclusion

The model of this paper entails heterogeneous producers with different productivity and wealth levels. With this model, an investigation is made to understand the impact of financial frictions on the economy's aggregate variables. Adding on to models in the related literature, this paper incorporates an alternative intermediate technology into the economy. Specifically, this intermediate technology provides the firm with a productivity level A_i that is higher than the entry-level technology but lags behind the frontier. The intermediate technology provides a more affordable cost than the frontier technology in terms of the adoption cost. Additionally, the model of this paper is structured so that all producers in the economy face financial friction in the form of a collateral constraint. Most of the quantitative section analysis dives into the impact of financial friction through the technological adoption channel, which prevents producers from efficiently upgrading their technology when there is an additional intermediate technology in the menu of technologies.

To provide some discipline to the quantitative analysis, the model has been matched to several key empirical moments: the debt to output ratio, equity to output ratio, economy's growth rate, and cross-country TFP difference. Data has been collated to understand three economies with different financial markets, where the US has the most well-developed level of the financial market, followed by Chile and then Egypt. Several results are in place after performing the calibration with these micro-level data. For one, zoning into the emerging economy of Chile, where it has a moderately developed financial market, most producers in the benchmark economy have an intermediate technology. On top of that, financial friction through the technological adoption channel of restricting producers from having sufficient capital to upgrade their technology has a sizable impact on aggregate variables in the economy.

However, compared with a Chilean benchmark economy with no intermediate technology, the economy with an intermediate technology has a more significant proportion of productive producers and exhibits higher levels in its aggregate variables for different θ levels. This forms the rationale that having an intermediate technology acts as a gateway for some producers to accumulate more wealth and eventually adopt productive technology. Another point of comparison for these two types of Chilean economy is that the decline in the aggregates is relatively more minor in an economy without intermediate technology. As Chile is an economy that relies heavily on intermediate technology in this model, tightening the constraint will severely impact aggregate variables in the economy with intermediate technology.

To extend further, a cross-country analysis is also performed with other countries exhibiting different levels of financial development. When comparing the quantitative results of Chile's small open economy with the US's financially well-developed large open economy, the quantitative results for the benchmark US economy detail a higher level of aggregate variables. As the interest rate is allowed to fluctuate in a large open economy for the US, quantitative analysis shows that interest rates decline as the collateral constraint tightens. Additionally, the US exhibits higher proportions of productive producers, with very few producers upgrading to the intermediate technology in the benchmark economy. This implies that a more developed financial market relates to more producers adopting the frontier technology and relying less on alternative intermediate technology. Although during bad times when θ decreases, having an intermediate technology for a large open economy of the US can buffer the losses to aggregate TFP and output levels. As for an economy that is not financially developed, Egypt's benchmark economy highlights that most of its producers stay with the entry-level technology. Although having an alternative intermediate technology in the technological ladder provides higher aggregate variables levels than a more financially developed Chile economy with no intermediate technology.

In the extension section of this paper, an investigation similar to papers that study misallocation due to dispersion of the marginal product of capital for producers in the economy is performed. The results show that having an intermediate technology reduces TFP losses attributed to this misallocation channel. This is because an alternative intermediate technology in the economy allows for a more efficient allocation of capital to more productive producers. Overall, the misallocation results align with the literature that explains that misallocation plays a relatively minor role in TFP losses.

Finally, the model of this paper closely mimicks the observed TFP patterns across Egypt, Chile, and the US. Whereby, most Chilean firms tend to adopt the technology that provides an intermediate TFP level relating to the data observation of Chile having a majority firms TFP level below the majority firm TFP level of the US and above the majority firm TFP level of Egypt. This paper also points to the primary analysis of the impact of financial friction through the technological adoption channel when an intermediate technology is introduced. The paper highlights that intermediate technology has a vital role by providing higher aggregate consumption, output, and TFP. For developed economies, intermediate technologies can help to buffer losses to aggregate TFP and output during crisis times.

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