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Persistent financial crises in emerging economies:

with endogenous R&D and adoption

개발도상국에서 장기간 지속되는 금융위기에 대한 분석

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Abstract

Persistent financial crises in emerging economies:

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This thesis explores the role of R&D, adoption, and productivity to explain why financial crises in emerging markets have more persistent and severe effects on output than other crises. The empirical analysis presents evidence that financial crises cripple R&D, productivity, and output more severely and persistently than other crises. In order to connect these crippled factors to output, a quantitative macroeconomic model was constructed on an international real business cycle model with endogenous R&D, adoption, and productivity. R&D and adoption activities were assumed to be subject to exogenous shocks, or major sources of emerging market business cycles. Since the rise of risk premium discourages the demand factors, R&D and adoption sectors suffer, and the growth of productivity and output are more severely deterred than otherwise. In conclusion, the main findings indicate that the endogenous total factor productivity mechanism amplifies the impact of financial crises on the demand factors to be more persistent and severe. More generally, this model analysis provides an insight into the relationship between exogenous technological changes and the changes of macroeconomic variables, which, despite its importance in the business cycles, has been under-researched. Thus, this model assigns a proper mechanism for the ad hoc relationship between an interest rate and productivity in the literature.

keywords : Financial crises, R&D, adoption, Business cycle
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Ⅰ. Introduction

The Global Financial Crisis was a reminder of the stylized fact that financial crises are followed by persistent downturns, whether they occur in advanced or developing countries. Reinhart and Rogoff (2009), Reinhart and Reinhart (2010), and Cerra and Saxena (2008) well document the slow recoveries from financial crises.

After this crisis, extensive literature emerged to explain these persistent downturns in advanced countries in two ways. A number of researchers emphasize the persistent fall of demand factors (Christiano et al. 2015). Some examine the deleveraging process while others analyze the constraints on macroeconomic policies. Though these demand factors must have played a significant role, they alone cannot explain the slow recoveries to the initial trend. Thus, several authors explore supply factors. Hall (2015) investigate the decrease of the capital stock while Reifschneider et al. (2015) add the drop in productivity to it. Reifschneider et al. (2015) conjecture that the endogenous decline in productivity-enhancing investment led to the drop in productivity. On the other hand, Garcia-Macia (2015) analyzes the misallocation of capital, and Decker et al. (2017) examine business dynamism as a source of the decline in productivity.

Indeed, the declines in productivity were observed multiple times worldwide in financial crises (Queralto, 2019; Huber 2018). Thus, this paper connects the decrease in productivity to persistent downturns after financial crises in emerging markets, assuming the decline of productivity could be endogenous. In particular, it focuses on productivity-enhancing investments (Comin and Gertler, 2006; Reifschneider, 2015; Anzoategui et al., 2019; Queralto, 2019). The endogenous drop in the investment from the crises could result in the subsequent decline of productivity.

However, most of the literature on emerging market business cycles has stressed financial frictions and exogenous technological shocks. Schimitt-Grohe and Uribe (2002) comprehensively examine small open economy models. Aguiar and Gopinath (2007) pioneer this literature by introducing a stochastic permanent technology process. But note that exogenous permanent technology shocks remain unknown. Neumeyer and Perri (2005), Fernandez-Villaverde et al. (2011), and

Chang and Fernandez (2013) accentuate the role of interest rates in business cycles. Lastly, Aguiar and Gopinath (2008) imply that this trend growth could be the result of frictions, such as financial frictions. According to Garcia-Cicco et al. (2010) and Fernandez and Gulan (2015), financial frictions could be important in explaining the business cycle of emerging economies.[1] However, this might not be the case with other channels that can replace the role of financial frictions.

Thus, this paper analyzes these crises in emerging markets (1) to verify whether R&D, adoption, and productivity are the source of the prolonged downturns as in advanced countries; and (2) to investigate the exogenous technological shocks.

Besides, many previous studies of emerging market business cycles emphasize the relationship between productivity and an interest rate for replicating emerging market business cycles. But they provide little justification for this relationship (Oviedo, 2005; Aguiar and Gopinath, 2008; Chang and Fernández, 2013). However, this is an evident relationship among R&D, adoption, and productivity. The change in macroeconomic variables will influence the decision of business sectors to invest in R&D and adoption. The change in R&D and adoption, in return, will inevitably affect productivity and output. Hence, this paper introduces these channels to assign a proper mechanism based on the literature of R&D investment (Crépon et al., 1998).

For these reasons, R&D, adoption, and productivity were assumed to be endogenous to answer these initiatives. Accordingly, this paper conducts an empirical analysis and constructs a quantitative macroeconomic model accordingly. Since the small open economy literature has been based on developing countries in Latin America, this paper focuses on them to confirm whether the new mechanism is applicable. The method of Romer and Romer (1989) was applied in the empirical analysis to identify the different effect of financial crises on R&D, adoption, and productivity. The data of Latin American countries were used here as the literature of emerging market business cycles.

As a result, the key findings indicate that financial crises have more persistent and severe impacts on total hours, labor productivity, and output. Furthermore, the

1) In addition, many other studies have explored the other possible sources of the business cycle, such as commodity demand or price (Fernandez et al., 2018; Drechsel and Tenreyro, 2018).

result suggests qualitative differences between the impact of financial crises and the other recessions. TFP, business R&D investment, and the number of patents showed more significant and permanent declines after financial crises. This implies that the differences are not from the size (quantity) of the shock, but from the quality.

Based on the empirical analysis results, a quantitative macroeconomic model was constructed to connect the decline in R&D, adoption, and productivity to the decrease in output. The whole model was built on an IRBC model with the endogenous TFP mechanism. Essentially, this model follows several seminal works in the business cycle of emerging countries. The basic structure of the small open economy model was employed with shocks that are widely known to be the crucial parts of the business cycle. Specifically, this paper focuses on risk premium shocks because they are crucial variables in the emerging market business cycles (Neumeyer and Perri, 2005; Fernandez-Villaverde et al., 2011; Chang and Fernandez, 2013). They were also used to represent financial shocks, especially in financial crises (Anzoategui et al., 2019; Queralto, 2019). Then financial frictions were introduced here to reflect the risk premium and debt burden. They were necessary due to their role in emerging markets and the stationarity of the model. Schimitt-Grohe and Uribe (2002) prove that such a condition is needed to guarantee the stationarity of the model. Aguiar and Gopinath (2008), Garcia-Cicco et al. (2010), and Fernandez and Gulan (2015) stress the importance of financial frictions.

Most importantly, the endogenous TFP mechanism was introduced into this model. The endogenous productivity mechanism implies that R&D, adoption, and TFP are no longer exogenous as in the IRBC literature. They are explicitly included in the model. This integration of the endogenous TFP mechanism and an IRBC model is the key feature that distinguishes this model from the literature. Especially an exogenous risk premium shock was included as the variable of focus to affect demand factors which, in return, influence R&D and adoption sectors and productivity. This is the part where this new mechanism magnifies the size and persistence of financial crises. In the following model, five types of agents exist: households, capital producers, researchers and adopters, and goods producers. Households maximize their utilities with the money borrowed from the world, labor income, the profit from goods producers, and more. Capital producers create

capital goods from final goods and sell it to households who rent it to intermediate-goods firms. TFP is created through two productivity-enhancing investments (Comin and Gertler, 2006): (1) R&D: the creation of new technologies and (2) Adoption: the conversion of these new technologies into usable ones. These two processes use skilled labor as an input. In turn, intermediate-goods producers who have access to the usable technology combine this with unskilled labor and utilized capital to produce their goods. In the end, a homogeneous final output is produced with an aggregate of intermediate goods. Note that the model with an exogenous TFP mechanism was also included to compare the result. Lastly, key parameters were borrowed from the IRBC literature.

Basically, this mechanism is based on the seminal literature of the endogenous TFP mechanism. Schmookler (1966) and Shleifer (1986) analyze the effect of aggregated demand on innovation. Romer (1990) and Comin and Gertler (2006) endogenize TFP. Romer (1990) uses the research sector, and later, Comin and Gertler (2006) add the adoption process to the research sector to reflect realistic lags in the creation of usable technology. Since then, many developments followed these seminal works. Comin et al. (2009) estimate a version of Comin and Gertler (2006), and Comin et al. (2014) propose a two-country framework between developing countries and advanced countries. Anzoategui et al. (2019), Queralto (2019), Guerron-Quintana and Jinnai (2014), and Garcia-Macia (2017) suggest endogenous growth mechanisms to explain the persistent financial crises. Comin and Gertler (2006), Anzoategui et al. (2019), Moran and Queralto (2018), and Bianchi, Kung, and Morales (2019) focus on this mechanism in advanced countries while this paper analyzes it in emerging countries.[2] This paper also differs by using business R&D expenditure and introducing financial frictions.[3] Though Ates and Saffie (2016) and Queralto (2019) examine this mechanism in emerging markets, they mainly stress borrowing frictions in banking crises and construct these frictions. However, this paper employs simple financial frictions as in the IRBC model and instead includes both banking crises and currency crises as financial crises.

2) Bianchi, Kung, and Morales (2019) construct a macroeconomic model with endogenous growth and estimate it with R&D data for the first time. However, the model of this paper focuses on developing countries and is more explicit. For a more detailed discussion, see Anzoategui et al. (2019).

3) Though Anzoategui et al. (2019) use business R&D expenditure, it does not have financial frictions.

Furthermore, this paper investigates adoption as well, which is consistent with the literature. Midrigan and Xu (2014) use emerging market firm-level data and empirically show that financial frictions harm productivity over the long run because they distort firm entry and technology adoption. According to them, it is much greater than misallocation across producers. However, unlike the previous study, this paper examines medium-run dynamics after financial crises and develops a quantitative model with macroeconomic variables. Also, the sample of interest is different. While Queralto (2019) examines the bigger cross country data for empirical analysis and South Korea for model analysis, this paper concentrates on Latin American countries because the IRBC literature is mostly based on them. In addition, this paper newly analyzes patent. Lastly, since the endogenous mechanism has its burden of complexity, this model abstracted from monetary policy and wage and price rigidities, unlike the literature (Anzoategui et al., 2019). Therefore, all the variables are in real terms as in the small open economy model literature.

On the other hand, note that Gertler et al. (2007), Mendoza (2010), and Mendoza and Yue (2012) examine financial crises in developing countries with quantitative frameworks. Some of them and others also explain the observed decline in TFP, capacity utilization, and more during financial crises.[4] But this paper accounts for how medium-run TFP declines and how they lead to persistent downturns. It also differentiates this paper from other quantitative analyses of financial crises in emerging markets. Most importantly, this paper is unique in that it examines R&D and adoption as a channel for such a phenomenon, though it can be seen as complementary to the past research.

In conclusion, this model analysis provides answers to the initiatives. As the risk premium rises in financial crises, the demands for consumption, capital investment, unskilled labor, and productivity-enhancing investments fall. Then the endogenous productivity channel amplifies financial crises more severe and persistent than other crises. This is consistent with the results of the empirical analysis. In contrast, the model with the exogenous productivity mechanism cannot explain the persistent downturns of productivity and output after financial crises. These results showed qualitative differences to the same size of the shock.

4) See Gopinath and Neiman (2014), Benjamin and Meza (2009), Meza and Quintin (2007), Kehoe and Ruhi (2009), Pratap and Urrutia (2012), and Aoki et al. (2009).

Moreover, note that both analyses are related to the IRBC literature that emphasizes large movements in exogenous productivity in emerging market business cycles. This paper shows how exogenous technology shocks can be endogenized and investigated. Thus, it provides a proper mechanism for the relationship between macroeconomic variables and productivity (Oviedo, 2005; Aguiar and Gopinath, 2008; Chang and Fernández, 2013).

The paper is organized as follows. Section I provides an introduction, and Section II presents the empirical analysis that shows qualitatively different behaviors of R&D and productivity to financial crises. Section III describes a quantitative macroeconomic model that connects the decrease in R&D, adoption, and productivity to persistent downturns after the crises, and Section IV presents an analysis of the model. Lastly, Section V provides concluding remarks.

Ⅱ. Empirical Analysis

2.1. Empirical Methodology

Empirically, the method of Romer and Romer (1989) was used here to identify the different impacts of financial crises and other crises on several macroeconomic variables.[5] The variables are real GDP, total hours, labor productivity, TFP, business R&D investment, and the number of utility patents. This method was used because the dynamic effects of a particular event can be estimated. In the following model, the changes in macroeconomic variables over time are captured as they are influenced by a particular type of crises. This method has an advantage in such event analysis (Romer and Romer, 1989; Cerra and Saxena, 2008; Queralto, 2019). Cerra and Saxena (2008) use a similar method to compare the impacts of financial rises relative to political crises while Queralto (2019) examines the impacts of financial crises on productivity-related variables. However, this paper differs from Cerra and Saxena (2008) because this analysis compares the impacts of financial crises and those of other economic crises. Also, there are differences between Queralto (2019) and this paper because this paper uses only the sample of developing countries in Latin America and newly analyzes patents.

5) Romer and Romer (1989) examine the shocks of monetary policies on the economy with industrial production and unemployment.

Note that this paper focuses on developing countries in Latin America, as the small open economy model literature did, to verify whether the new mechanism is applicable.

In particular, a univariate autoregressive model was estimated to account for serial correlation in growth rates.[6] Also, growth rates were used due to the nonstationarity of output (Charles Nelson and Charles Plosser, 1982).[7] The equation for an economy i (i= 1, ..., 5) is as follows:

$$x_{i,t} = \alpha_i + \sum_{j=1}^{J} \beta_j x_{i,t-j} + \sum_{k=0}^{K} \gamma_k D_{i,t-k} + \epsilon_{i,t} \qquad (1)$$

where $x_{i,t}$ is the percentage growth rate of a macroeconomic variable, α_i is a country fixed effect, and $D_{i,t}$ is a dummy variable or a qualitative indicator of economic crises. Since F-tests indicated the presence of country fixed effects, they were included to control for the country-specific factor that is not reflected in the model but affects the variable of interest.[8] Then the lags J and K were included to reflect the current and lagged impacts, and they were selected to be 1 and 5 from Akaike Infomation Criterion and Bayesian Information Criterion. However, the result was robust to other selection of lags.

Accordingly, impulse responses were estimated to the event of a particular economic crisis with cross country panel data, and the group averages of the responses were provided with a one standard error band drawn from a thousand Monte Carlo simulations. Thus, it shows how a particular type of economic crises can affect macroeconomic variables statistically.

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6) Levin-Lin-Chu panel unit roots tests were conducted. The lags were selected from Akaike Information Criterion with at most ten lags. The test suggested the presence of unit roots in real GDP, TFP, and labor productivity.

7) To facilitate the interpretation between variables, other stationary variables were also changed into growth rates.

8) Though there are correlations between the country fixed effects and the lagged dependent variables, it is likely to be small with low persistence (Stephen Nickell, 1981; Ruth Judson and Ann Owen, 1999).

2.2. Data

The estimation used balanced cross-country panel data from 1951 to 2017. Only the data on business R&D investment and the number of patents are from 1996 to 2017 and from 1992 to 2017, respectively. The country included several Latin American countries such as Argentina, Brazil, Chile, Colombia, and Mexico. The data used are real GDP, total hours, TFP, labor productivity, business R&D investment, the number of utility patents granted, and the qualitative measure of financial crises and the other recessions. Here total hours were constructed by multiplying average working hours with the number of employed people. Labor productivity was built on real GDP by dividing it with total hours. The qualitative indicator of the other recessions was constructed in a way similar to setting OECD based Recession Indicators.[9)]

Real GDP, TFP, average working hours, and the number of employed people were obtained from Feenstra et al. (2015). Business R&D investment from the UNESCO Institute for Statistics. The number of patents from the United States Patent and Trademark Office (USPTO). The qualitative indicator of financial crises from Laeven and Valencia (2013). Only business R&D investment was selected based on the source of the investment because it is the focus of the whole paper. The number of patents was assigned to each country based on the first inventor's address as in the literature. Also, only utility patents were used because they are known as patents for inventions. Laeven and Valencia (2013) document baking crises and currency crises worldwide from 1970 to 2016. The qualitative measure of financial crises was constructed as the sum of these two types of crises.

These variables were included as the main variables of interest. Real GDP was included since it is the best indicator of economic activities. Labor productivity, TFP, business R&D investment, and the number of patents were investigated because they are the main topic of this paper. The number of patents is the indicator for the input as well as the output because the patents are not only the result of R&D activities but also the resource of productivity (Lee, 2013). Sometimes several patents become obsolete with few citations. Here real GDP was decomposed into labor productivity and total hours, and they were used to

9) See Appendix for further details.

examine the impact of financial crises and the other recessions following the equation (Queralto, 2019):

$$\log Y_{i,t} = \log Y_{i,t}/N_{i,t} + \log N_{i,t} \tag{2}$$

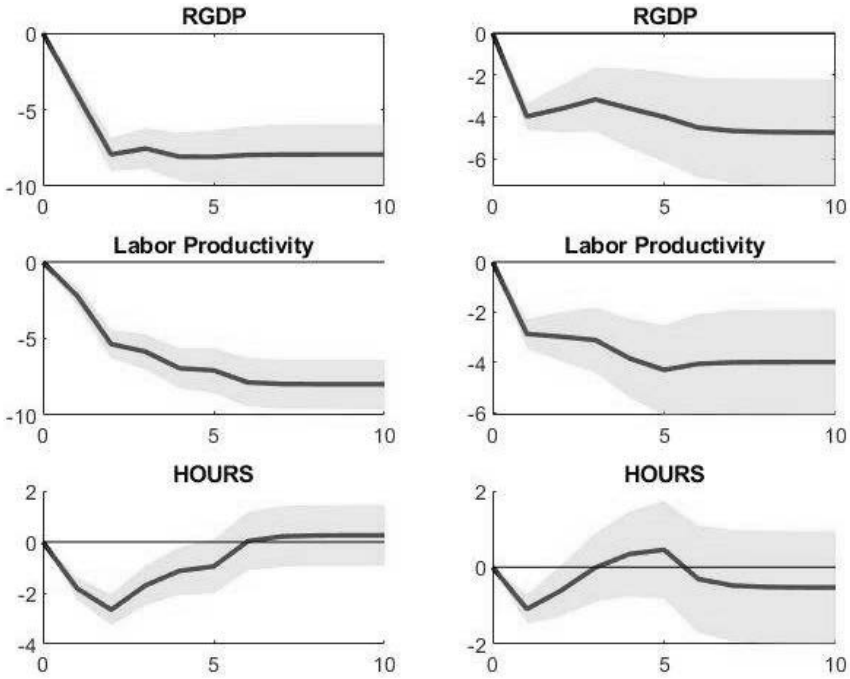
However, business R&D investment and the number of patents were employed to identify qualitative differences between financial crises and the other recessions. Lastly, note that all the data are in real terms. Thus, the impulse responses of every variable are set to 100 in period 0 (benchmark), and the changes are in terms of percentage.

2.3. Estimation Results

Figure 1 reports the results, the impulse responses of macroeconomic variables – output, total hours, and labor productivity – to the event of financial crises or the other recessions. The left column shows the responses to financial crises while the right column provides the responses to the other recessions. The responding variable names are denoted at the top of each graph, and the responses were estimated over ten years.

The first row of Figure 1 indicates that the output decreases more deeply and persistently in financial crises than the other recessions. Real GDP in financial crises decreases by approximately 8% after four years while real GDP in the others declines by around 4% after five years. The declines of real GDP in both cases are significant and persistent as in the literature (Cerra and Saxena, 2008; Queralto, 2019). Also, the second and third rows imply that the responses of labor productivity and total hours are more severe and persistent in financial crises. Labor productivity in financial crises decreases by approximately 8% after six years while that in the other recessions declines by around 4% after five years. The losses of labor productivity in both crises are not only significant but also long-lasting. Total hours in financial crises decline by 3% after two years, but the losses become insignificant after five years. However, total hours in the other recessions decrease by 1% in a year, but the decline becomes insignificant after two years.

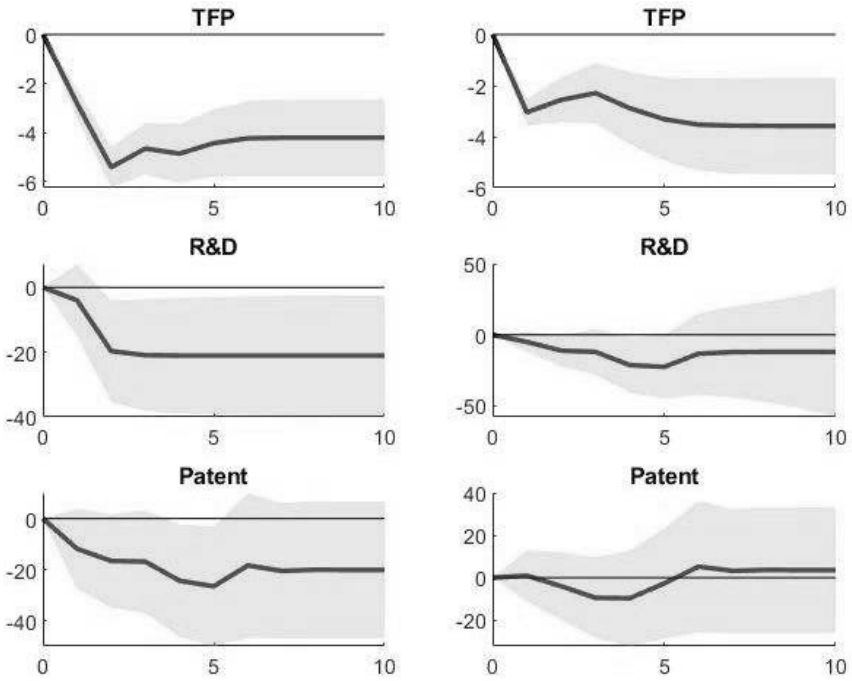
Figure 1. Impulse responses of real GDP and its components



In summation, financial crises have more persistent and severe impacts on total hours and labor productivity. Therefore, output decreases more permanently and severely in financial crises. This is well indicated by the decomposition of output, eq (2). The interesting point is that the response of labor productivity accounts for the response of output better than that of total hours.

However, these differences might have originated from the size of the shocks. In other words, the negative shocks might have been much bigger in financial crises, and the size difference could have led to such different results. For this reason, it was necessary to identify qualitative differences that, unlike the other recessions, financial crises, in particular, devastate R&D and productivity. Thus, the same methodology was applied to estimate the responses of TFP, business R&D, and the number of patents. Here TFP was used instead of labor productivity because it is relatively more exogenous than the other. Figure 2 summarizes the result as before with each column showing the responses to financial crises and the other recessions, respectively.

Figure 2. Impulse response of TFP, R&D investment, and the number of patents



The first row of Figure 2 implies that the decline of TFP in financial crises is bigger. TFP in financial crises decreases by around 5% after two years while that in the other recessions reduces by approximately 4% after five years. The losses in both crises are permanent and significant. The second row and the third row also show that business R&D investment and the number of patents decrease more permanently and deeply in financial crises. Business R&D investment in financial crises diminishes by approximately 21% after four years, and the losses are significant for the whole period except for the first year. However, the investment in the other recessions decreases by around 21% after four years, but the responses are significant only for the second, fourth, and fifth year. Moreover, the patent number in financial crises declines by approximately 25% after four years, and the decline is significant for the fourth and fifth years. The patent number in the other recessions reduces by around 10% after three years, but the whole response is insignificant.

To summarize, the result seems consistent with the literature (Cerra and

Saxena, 2008; Queralto, 2019). Most importantly, the responses of TFP, business R&D investment, and the patent number suggest that unlike the other recessions, financial crises paralyze R&D and productivity. Accordingly, a quantitative macroeconomic model was built on this finding to connect the dots - to link the decline of R&D, productivity, and output.

Ⅲ. Model

3.1. The model with endogenous productivity

3.1.1. Households

There is a continuum of measure one of representative households, and each household h has a unit measure of members. It consumes, saves and rents capital to intermediate-goods firms, and borrows from foreign investors.

Moreover, the household's problem has unique features when compared to that of the standard model. First, there is a slight difference in the structure of preference from the IRBC literature. The term, X_t, in the disutility of labor depends on the aggregate technological level, A_t, as follows: $X_t = A_t^{\gamma} X_{t-1}^{1-\gamma}$, $0 < \gamma \leq 1$. If $X_t = 1$ (a constant) as Greenwood et al. (1988) (GHH preference), this could be a problem because it implies a trend growth in working hours though there is a physical limit. Besides, X_t could be used to follow a balanced growth path. Thus, the preference of Jaimovich and Rebelo (2009) was used here. Also, they showed that with small γ, this preference is consistent with the GHH preference. Variations in A_t will have a short-run wealth effect on labor supply or a small medium-run impact on labor supply.[10] Therefore, a rise in an interest rate does not lead to an increase in labor supply, which discourages counter-factual booms in employment and output.

Second, although the household h is a monopolistically competitive supplier of labor as in standard set-ups, there exist two types of labor. This distinction was made to consider innovation and adoption effort in the model as illustrated in

10) See Jaimovich and Rebelo (2009) for more information on this type of preference.

Anzoategui et al. (2019): unskilled labor, L_{ut}, for the production of intermediate-goods; and skilled labor, L_{st}, for R&D or adoption by innovators and adopters. As in the standard models, monopolistically competitive employment agencies aggregate each type of labor into a homogenous labor input:

$$L_{it} = \left(\int_0^1 \left(L_{it}^h\right)^{\frac{1}{\mu_{ut}}} dh \right)^{\mu_{ut}}, \ i = u, s \tag{3}$$

where μ_{wt} is the elasticity of substitution across labor types and follows an exogenous autoregressive process of order 1 (AR (1) process):

$$\log(\mu_{wt}) = (1-\rho_{\mu_w})\mu_w + \rho_{\mu_w}\log(\mu_{wt-1}) + \sigma_{\mu_w}\epsilon_t^{\mu_w}, \ \epsilon_t^{\mu_w} \sim \textbf{\textit{iid}} \tag{4}$$

From employment agencies' cost minimization, the demand for L_{it}^h is given by

$$L_{it}^h = (w_{i[t}/w_t)^{\mu_{ut}/(\mu_{ut}-1)} L_{it} \ \textbf{where} \ w_{it} = \left(\int_0^1 (w_{it})^{1/(1-\mu_{ut})} dh\right)^{1-\mu_{ut}}, \tag{5}$$

i = u, s and w_{it} is the real wage of labor type i.[11]

Let C_t be consumption, B_t total domestic debt held by foreign investors, Π_t profits from the ownership of firms, K_t capital stock, D_t the rental rate of capital, and Q_t the price of capital. Then the households make decisions:

$$\max_{C_{t+\tau}, B_{t+\tau}, L_{ut+\tau}, L_{st+\tau}, K_{t+1+\tau}} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left\{ \frac{\left(C_{t+\tau} - \frac{\theta_1}{w_1} X_{t+\tau} \left(L_{ut+\tau}\right)^{w_1} - \frac{\theta_2}{w_1} X_{t+\tau} \left(L_{st+\tau}\right)^{w_1} \right)^{1-\sigma} - 1}{1-\sigma} \right\} \tag{6}$$

$$\textbf{subject to} \ B_t + w_{ut}L_{ut} + w_{st}L_{st} + \Pi_t + R_{kt}Q_{t-1}K_t = Q_t K_{t+1} + R_{t-1}B_{t-1} + C_t \tag{7}$$

where the rate of return, $R_{kt} \equiv (D_t + Q_t)/Q_{t-1}$ and the household's stochastic discount factor, $\Lambda_{t,t+1} \equiv \beta u'(C_{t+1})/u'(C_t)$. The first-order conditions for B_t and K_{t+1} are, respectively:

$$E_t \Lambda_{t,t+1} R_t = 1 \tag{8}$$

11) From this point, the superscript h will often be omitted since each agent makes the symmetric decision in the equilibrium.

$$E_t \Lambda_{t,t+1} R_{kt+1} = 1 \tag{9}$$

The interest rate, R_t, consists of the steady-state world interest rate, R, borrowing frictions, $\overline{\Psi}\{\exp(B_t/Y_t - \overline{d}) - 1\}$, and an exogenous risk premium, μ_t^r. The frictions or the risk premium parts (8) consist of the ratio of debt to output, B_t/Y_t, and a random risk premium shock, μ_t^r. This mechanism is introduced to include simple financial frictions and to ensure stationary dynamics as in the small open economy model literature (Schimitt-Grohe and Uribe, 2002). The random risk premium disturbance, μ_t^r, is assumed to follow an AR(1) process:

$$R_t = R + \overline{\Psi}\{\exp(B_t/Y_t - \overline{d}) - 1\} + \exp(\mu_t^r) - 1 \tag{10}$$

$$\text{where } \mu_t^r = \rho_r \mu_{t-1}^r + \sigma_r \epsilon_t^r,\ \epsilon_t^r \text{~iid} \tag{11}$$

3.1.2. Capital Producers

Capital producers make new capital goods, I_t, using final goods, and they sell these goods to households. Let p_{kt} be the relative price of making new capital out of new capital goods, the logarithm of which is assumed to follow an AR(1) process without a constant term. The investment adjustment costs, $s(\cdot)$ were assumed to include realistic lags in the evolution of capitals. Then, capital producers' optimization problem is:

$$\max_{I_t} E_t \sum_{\tau=0}^{\infty} \Lambda_{t,\ t+\tau} \left[Q_{t+\tau} I_{t+\tau} - \left\{ 1 + s\left(\frac{I_{t+\tau}}{I_{t+\tau-1}} \right) \right\} I_{t+\tau} p_{kt+\tau} \right]$$

The first-order condition provides the relationship between the ratio of Q_t to p_{kt} and investment. The ratio on the left-hand side can be interpreted as Tobin's Q:[12)]

$$\begin{aligned} \frac{Q_t}{p_{kt}} = 1 + s\left(\frac{I_t}{(1+\gamma_y) I_{t-1}} \right) + \frac{I_t}{(1+\gamma_y) I_{t-1}} s'\left(\frac{I_t}{(1+\gamma_y) I_{t-1}} \right) \\ - E_t \Lambda_{t,\ t+1} \left(\frac{I_{t+1}}{(1+\gamma_y) I_t} \right)^2 s'\left(\frac{I_{t+1}}{(1+\gamma_y) I_t} \right) p_{kt+1} (1+\gamma_y) / p_{kt} \Lambda_{t,t} \end{aligned} \tag{12}$$

12) The ratio between the market value of a physical asset and its replacement value.

The law of motion for capital is

$$K_{t+1} = I_t + (1-\delta(U_t))K_t \tag{13}$$

3.1.3. Production Sector

To introduce the endogenous productivity mechanism, this model constructs the production sector in a way similar to that of Comin and Gertler (2006) and Anzoategui et al. (2019). Two types of mopolistically competitive firms exist in goods production; intermediate-goods producers produce materials for final-goods producers. Final-goods production consists of a continuum of producers whose measure is unity, and each of the firms i produces a differentiated output, Y_t^i, by using a unit of intermediate-goods composite, Y_{mt}^i, as input: $Y_t^i = Y_{mt}^i$

Then, a final good composite is constructed as the aggregate of the differentiated final goods:

$$Y_t = \left(\int_0^1 \left(Y_t^i\right)^{\frac{1}{\mu_t}} di\right)^{\mu_t}, \ \mu_t > 1 \tag{14}$$

where $\log(\mu_t)$ follows an AR(1) process:

$$\log(\mu_t) = (1-\rho_\mu)\mu + \rho_\mu \log(\mu_{t-1}) + \sigma_\mu \epsilon_t^\mu, \quad \epsilon_t^\mu \sim iid \tag{15}$$

However, this paper abstracts from staggered price or wage setting to make all the prices perfectly flexible as in the small open economy model literature because the endogenous productivity mechanism has its burden on complexity. Note that it does not obscure the critical results of this paper. Thus,

$$MC_t \mu_t = 1, \ \ MC_t = p_{mt} / A_t^{v-1} \tag{16}$$

where MC_t is the marginal cost of final goods firms, μ_t price markup, and p_{mt} the relative price of the intermediate-goods composite.

On the other hand, there is a continuum of competitive intermediate-goods firms, with the measure A_t, which makes a differentiated product, respectively. A_t is the aggregate of technologies adopted or productivity. This variable will be endogenously predetermined by R&D and adoption sectors in the following section.

The intermediate-goods composite is the aggregate of individual intermediate goods, Y_{mt}^{j} :

$$Y_{mt} = (\int_{0}^{A_t} (Y_{mt}^{j})^{1/\upsilon})^{\upsilon}, \ \textbf{\textit{with}} \ \upsilon > 1 \tag{17}$$

Let U_t^j be the degree to which the capital is used by firm *j*, K_t^j be the stock of capital firm *j* employs, and L_{ut}^j the stock of unskilled labor firm *j* employs. Anzoategui et al. (2019) argue that one can avoid ascribing all high-frequency variation in the Solow residual to endogenous productivity by introducing capital utilization intensity, U_t^j. Then each intermediate goods firm *j* uses capital services $U_t^j K_t^j$ and unskilled labor L_{ut}^j to produce intermediate goods Y_{mt}^j according to the following Cobb-Douglas production function:

$$Y_{mt}^{j} = \theta_t (U_t^j K_t^j)^{\alpha} (L_{ut}^j)^{1-\alpha} \tag{18}$$

where θ_t is a TFP shock:[13] $\log(\theta_t) = \rho_\theta \log(\theta_{t-1}) + \sigma_\theta \epsilon_t^\theta, \ \epsilon_t^\theta \sim iid$ (19)

Since intermediate goods become symmetric, the aggregate production function for the final output Y_t can be expressed as:

$$Y_t \approx Y_{mt} = \left(A_t^{\vartheta-1}\theta_t\right)\left(U_t K_t\right)^{\alpha}\left(L_{ut}\right)^{1-\alpha} \text{[14]} \tag{20}$$

The term in the first parentheses is the TFP, the product of $A_t^{\upsilon-1}$ that reflects endogenous productivity and θ_t that indicates exogenous variation. Overall, endogenous productivity effects enter into production through the aggregate of adopted technologies, A_t while θ_t was assumed stationary to make the endogenous productivity mechanism as the driving force of long-term growth.

Also, an intermediate-goods firm *j* creates factor demands as it chooses K_t^j, U_t^j, and L_{ut}^j to minimize its production cost, given p_{mt}, Q_t, D_t, w_{ut}, and the desired markup, ζ. This paper endogenizes the firm's capital utilization decision by making the depreciation rate $\delta(U_t^j)$ a function of capital utilization rate, U_t^j (Greenwood et al., 1988; Anzoategui et al., 2019). Moreover, working capital restrictions for intermediate-goods producers, w_t^r exist to enhance the quantitative

13) Since A_t is assumed to have no exogenous shock due to the data availability issue, the variation of θ_t becomes the TFP shock.

14) See Appendix for further details.

performance and introduce the endogenous mechanism in a small open economy model (Queralto, 2019). Then, the firm' s cost minimization problem for K_t^j, U_t^j, and L_{ut}^j gives:

$$\varsigma\omega_t^r = \frac{(1-\alpha)MMC_t^j Y_{mt}^j}{L_{ut}^j},$$

$$\varsigma\delta'\left(U_t^j\right)Q_t K_t^j = \frac{\alpha MMC_t^j Y_{mt}^j}{U_t^j},\ \varsigma\left(D_t + \delta\left(U_t^j\right)Q_t\right) = \frac{\alpha MMC_t^j Y_{mt}^j}{K_t^j} \tag{21}$$

Here, the desired markup was assumed to be smaller than the optimal markup ϑ to avoid the threat of imitators' entry (Aghion and Howitt, 1997; Anzoategui et al., 2019).

3.1.4. Innovators and adopters

This section is where productivity becomes endogenous (Comin and Gertler, 2006; Anzoategui et al., 2019). The process of innovation is divided into two parts to reflect realistic lags in technology adoption: creating new technologies and adopting some of them. Thus, R&D expenditure increases the stock of technologies, Z_t, while adoption expenditure increases the stock of adopted technologies, A_t. Accordingly, there are innovators and adopters in the R&D sector and the adoption sector, respectively.

1) Innovators: Z_t as a result of R&D

A continuum, measure unity, of innovators creates new technologies with skilled labor. L_{srt}^p indicates skilled labor employed by an innovator p in R&D, and L_{srt} the aggregate of L_{srt}^p, which an individual innovator takes as given. Then a unit of skilled labor at t create Φ_t, the number of new technologies at $t+1$:

$$\Phi_t = \chi_t Z_t L_{srt}^{\rho_z - 1} \tag{22}$$

where χ_t ***is a random shock:***

$$\log(\chi_t) = (1-\rho_\chi)\chi + \rho_\chi \log(\chi_{t-1}) + \sigma_\chi \epsilon_t^\chi,\ \epsilon_t^\mu \sim iid \tag{23}$$

Based on Romer (1990), Z_t reflects public knowledge in the R&D process which the innovator also accepts as given. Besides, it is assumed $\rho_z < 1$ since constant returns to scale in R&D at the individual innovator level simplifies the aggregation of individual R&D. However, the marginal increase in the efficiency of R&D diminishes as the aggregate R&D increases at the aggregate level. Thus, innovator p' s decision problem can be expressed as:

$$\max_{L_{srt}^p} E_t\left\{\Lambda_{t,\ t+1} J_{t+1} \Phi_t L_{srt}^p\right\} - w_{st} L_{srt}^p$$

where J_t is the value of an unadopted technology. This gives

$$E_t\left\{\Lambda_{t,\ t+1} J_{t+1} \chi_t Z_t L_{srt}^{\rho_z - 1}\right\} = w_{st}. \tag{24}$$

The left-hand side is the marginal benefit, and the right-hand side is the marginal cost. Note that J_t and L_{srt} exhibit procyclical movements since profits from intermediate goods are procyclical, and J_t depends on expected future profits.

For a realistic approach, this model further includes technological obsolescence. The evolution of technologies is represented as: $Z_{t+1} = \Phi_t L_{srt} + \phi Z_t$, where ϕ is the survival rate for the technology of time *t,* and the first term $\Phi_t L_{srt}$ reflects the creation of new technologies by the aggregate number of skilled labor working in the R&D sector. This evolution can also be expressed as $Z_{t+1}/Z_t = \chi_t L_{srt}^{\rho_z} + \phi$ to verify that ρ_z is the elasticity of the growth rate of R&D technologies to the skilled labor in R&D.

2) Adopters: A_t as a result of Technology Adoption

The stock of technologies Z_t cannot affect productivity yet since this stock of technologies has to be converted into A_t through adoption. An adopter converts unadopted technologies into usable ones. A competitive aggregate of adopters was

assumed to facilitate summation. They buy the unadopted technology from the innovators at the competitive price, J_t. Subsequently, they use skilled labor to convert this technology into a usable one.

Here, such adoption process, or technology diffusion, was assumed to take time on average (Comin and Hobijn, 2010), and the adoption rate to change endogenously (Comin, 2009; Anzoategui et al. 2019). The speed of adoption depends on Z_t and L_{sat} that are used in adoption. The probability of success in making the technology usable in any given period is $\lambda_t = \lambda(Z_t L_{sat})$ with $\lambda' > 0$, $\lambda'' < 0$. It implies that the adoption process becomes more efficient by a spillover effect as the economy's general technological level enhances. This spillover is conducive to constructing the model since it guarantees a balanced growth path. Moreover, the reciprocal of this probability can represent the average adoption process time. If this probability is not on the steady-state value $\bar{\lambda}$, the speed of adoption will change as L_{sat} does. Lastly, unlike the R&D effort, no exogenous shock was assumed to the output of adoption activities, productivity, due to the lack of relevant data.

Once the technology becomes usable through adoption, the right to it is sold to an intermediate-goods producer. If Π_{mt} indicates the profits of this firm that result from its monopolistically competitive pricing on the good it produces, then the value of the adopted technology,

$$V_t = \Pi_{mt} + \phi E_t\{\Lambda_{t,\ t+1} V_{t+1}\}. \tag{25}$$

The right-hand side is the present value of profits from producing intermediate-goods. Hence, the adopter's maximization problem becomes:

$$J_t = \max_{L_{sat}} E_t\{-w_{st} L_{sat} + \phi \Lambda_{t,\ t+1}[\lambda_t V_{t+1} + (1-\lambda_t) J_{t+1}]\} \tag{26}$$

This recursive equation consists of total adoption cost and the total discounted benefit. The first-order condition is:

$$\lambda' \phi E_t\{\Lambda_{t,\ t+1}[V_{t+1} - J_{t+1}]\} = w_{st} \tag{27}$$

The left-hand side is the marginal benefit from additional adoption while the

right-hand side represents the marginal cost. Note that $V_t - J_t$ is procyclical as the value of adopted technologies is more strongly affected by short term profits than unadopted ones. Therefore, L_{sat} and accordingly, the pace of adoption changes procyclically.

Since λ_t is independent of individual-specific characteristics, the summation across adopters provides the evolution of adopted technologies:

$$A_{t+1} = \lambda_t \phi [Z_t - A_t] + \phi A_t \tag{28}$$

where $Z_t - A_t$ is the stock of unadopted technologies.

3.1.5. Equilibrium conditions

The resource constraint can be obtained by putting the equilibrium conditions into the household budget constraint.

$$Y_t = C_t + Q_t I_t + R_{t-1} B_{t-1} - B_t - w_{st} L_{st} + w_t^r L_{ut} \tag{29}$$

The market-clearing condition for skilled labor is

$$L_{st} = (Z_t - A_t) L_{sat} + L_{srt} \tag{30}$$

Trade balance depends on total domestic debt:

$$TB_t = R_{t-1} B_{t-1} - B_t \tag{31}$$

Finally, the model with the endogenous productivity channel features long-run growth in aggregate TFP and output (Anzoategui et al., 2019; Queralto, 2019).

3.2. The model with exogenous productivity

The analysis of the standard small open economy model is necessary to compare the result with that of the model above. All parts of the model are the same as above except the parts related to A_t. The growth rate of A_t was assumed to follow an exogenous process as in the literature (Aguiar and Gopinath, 2007):

$$g_t = A_{t+1}/A_t, \ \log(g_t/\mu_g) = \rho_g \log(g_{t-1}/\mu_g) + \sigma_g \epsilon_t^g \ \textbf{\textit{where}} \ \epsilon_t^g \sim \textbf{\textit{iid}} \tag{32}$$

Table 1. Calibrated Parameters

Parameter	Description	Value
R	Gross foreign interest rate	1.0025
δ	Capital depreciation rate	1.03^4-1
ω	Elasticity of marginal depreciation to utilization	0.006
α	Share of capital	0.3132
σ	Intertemporal elasticity of substitution	2
w_1	Frisch labor supply elasticity	1.6
ρ_λ	Adoption elasticity	0.925
ζ	Steady-state intermediate-goods markup	1.18
$\overline{d}$	Foreign Debt-to-trend ratio	0.007
λ	Adoption lag	0.2/4
θ_w	Working capital requirement	1

Ⅳ. Model Analysis

The macroeconomic models were solved in two stages: they were detrended to obtain stationary systems; and they were log-linearly approximated around the steady-state of those stationary systems.

4.1. Parameters

4.1.1. Calibrated parameters

The calibrated parameters are summarized in Table 1. Gross foreign interest rate is from Chang and Fernández (2013), the depreciation rate of capital, Frisch labor supply elasticity, and foreign debt-to-trend ratio from Garcia-Cicco et al. (2010), the elasticity of marginal depreciation to utilization and working capital requirements from Queralto (2019), the share of capital in the production function and intertemporal elasticity of substitution from both Garcia-Cicco et al. (2010) and Chang and Fernández (2013), adoption elasticity, steady-state intermediate-goods markup, and adoption lag from Anzoategui et al. (2019).

Note that $\upsilon = 2-\alpha$ to make this model follow a balanced growth path (Kung and Schmid, 2015; Queralto, 2019). This parametrization makes the endogenous productivity into pure labor productivity. However, some parameters on the

adoption process were borrowed from Anzoategui et al. (2019) due to the lack of relevant data.

4.2. Result Analyses - Why endogenous productivity?

This paper has three initiatives: to explain the persistent and severe downturns after financial crises; to examine exogenous technology shocks which have been stressed in the literature; and to assign a proper mechanism for the relationship between an interest rate and productivity in the literature. In order to find answers, this paper examines productivity with the assumption that it is endogenous.

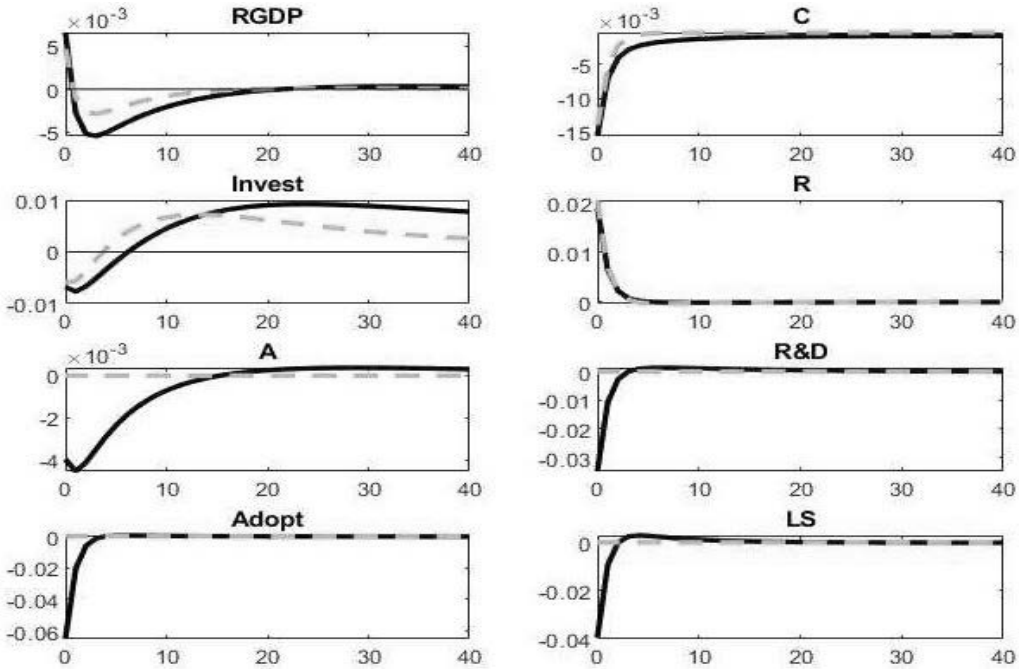
4.2.1. Persistent and severe downturns

1) Counter-factual analysis

Most importantly, it should be verified whether endogenous productivity is conducive to explaining more persistent and severe downturns following financial crises. Thus, a counter-factual analysis follows. In the counterpart model, productivity was assumed exogenous as in section 3.2. Figure 3 shows the economy' s dynamics to an exogenous shock: a rise in the country risk premium. Specifically, this paper focuses on a risk premium shock because it is a crucial variable in the business cycles of emerging markets (Neumeyer and Perri, 2005; Fernandez-Villaverde et al., 2011; and Chang and Fernandez, 2013).

Also, note that they were used to represent financial shocks, especially in financial crises (Anzoategui et al., 2019; Queralto, 2019). The figure summarizes several macroeconomic variables' impulse responses to the one standard error risk premium shocks. The names of responding variables are denoted at the top. The graph named R depicts the response of the epicenter variable. The rest of the figure describes the responses of output, consumption, and investment as well as three key productivity-related variables - the aggregate productivity, the R&D expenditure, and the adoption expenditure. Note that all the responses represent the percent changes from the steady-state value in quarterly frequencies. The

Figure 3. Impulse responses of macroeconomic variables to the risk premium shock



straight lines are the impulse responses of the model with the endogenous productivity while the dotted lines are those of the standard model with the exogenous productivity.

From the response of R, the shocks can be identified. To the one standard error risk premium shocks, real interest rates in both models rise to approximately 0.02% and return to the initial level in five quarters. Note that this similarity is necessary because the difference should be qualitative, not quantitative. In other words, if the shocks were bigger in the model with endogenous productivity, it would not be reasonable to compare the responses because the difference could come from the different sizes of the shocks. In response to these shocks, consumption and capital investment decrease more severely and persistently in the endogenous productivity model. The consumption in the endogenous productivity model decreases by approximately 0.02% while that of the exogenous productivity model diminishes by around 0.01%. The capital investments in both models drop by around 0.01%, but the drop is bigger in the former. Also, the returns of both

variables to the initial level are much slower in the model with endogenous productivity. In case of the capital investments, it is after seven and four quarters, respectively.

Furthermore, business R&D investment and adoption expenditure in the model with endogenous productivity plummeted by approximately 0.03% and 0.06%. They return to the initial level in five quarters. However, such a drop in R&D and adoption expenditure cannot be found in the other model because these factors were assumed exogenous literally. Accordingly, productivity in the model with exogenous productivity does not change much. This, in the end, results in more persistent and severe impacts on output. Real GDP in the endogenous productivity model decreases by approximately 0.005% while that in the exogenous productivity model diminishes by around 0.003%. Though real GDP returns to the original level eventually, it takes longer in the endogenous productivity model. It takes 21 quarters in the endogenous productivity model while it is 19 quarters in the other. As it is represented in eq (20) and (29), output decreases more severely and permanently in the endogenous productivity model.

In summation, these two models show qualitatively different reactions to the same shock. Specifically, the model with the endogenous productivity channel better captures the response of R&D, adoption, productivity, and output after financial crises. It verifies how R&D and adoption are damaged to the risk premium shocks and how this damage leads to the persistent and severe decline in output. Moreover, the results are consistent with the literature (Anzoategui et al., 2019; Queralto, 2019).

2) Why so different?

Indeed, the endogenous productivity model and the exogenous productivity model have different results. Thus, it is necessary to examine how the endogenous productivity model leads to such differences. To summarize, the main source of the differences is productivity.

The initiating disturbance to the country risk premium, all else equal, induces the exogenous risk premium to rise according to eq (11). As a result, the real interest rate increases following eq (10). Then, in response to the increase in the

real interest rate, households reduce their demand for consumption and risky saving. This is well represented in eq (8). The rise of the interest rate leads to the decline of the stochastic discount factor, which decreases consumption demand and increases the required return to capital. As a result, it leads to a drop in demand for capital investment and productivity-enhancing efforts by harshly discounting future profits. This can be verified in eq (24) and (26). Also, the demand for unskilled labor wanes as the working capital restrictions increase the cost of the labor input.

The result, the decline in output can be understood in two ways. According to the resource constraint, eq (29), the fall in capital investment and consumption demand reduces the output. However, the production function of intermediate goods firms, eq (20), shows that the drop in capital investment and unskilled labor demand decreases the output. Here the drop in unskilled labor demand comes from working capital restrictions.

Furthermore, the drop in productivity-enhancing investments harms productivity, amplifying the decline of output to be more persistent and severe than the model with exogenous technology. As a result, aggregate demand and output drop in the short term. However, in the medium and long term, the growth rates and levels of TFP and real GDP decline to larger scales. To summarize, the endogenous productivity channel plays a significant role in amplifying the country' s premium shock effect.

4.2.2. Productivity and an interest rate

This model provides a proper mechanism that was ad hoc in the literature by endogenously considering R&D, adoption, and productivity. Oviedo (2005), Aguiar and Gopinath (2008), and Chang and Fernández (2013) argue that a link between productivity and the interest rate is necessary to build models replicating emerging market business cycles. However, this relationship is evident since macroeconomic variables affect R&D, adoption, and, accordingly, productivity. Most importantly, this result explains what exogenous technological shocks can be because the change of a macroeconomic variable affects productivity-enhancing investment and productivity.

Ⅴ. Conclusion

This paper identifies qualitative differences in the behaviors of R&D, adoption, and productivity between financial crises and the other recessions. Then it constructs a quantitative macroeconomic model to connect the qualitative differences to persistent and severe downturns after financial crises. The main findings indicate that the decline of R&D, adoption, and productivity can explain the persistent and deep recessions after financial crises. This result is consistent with the literature (Anzoategui, D. et al., 2019; Queralto, 2019). In contrast, the result suggests that the exogenous productivity mechanism has a limited role in explaining the downturns of productivity and output after financial crises.

Also, this endogenous productivity mechanism explains how exogenous technological shocks could result in a change in productivity. Thus, it assigns a proper relationship between productivity and an interest rate that was ad hoc in the literature (Oviedo, 2005; Aguiar and Gopinath, 2008; Chang and Fernández, 2013).

However, there is still room for improvement. First, it would be a great advancement to finish the estimation of the macroeconomic model and develop the paper based on the result. Second, it is also desirable to collect the data on adoption and analyze it as in Anzoategui, D. et al. (2019). It requires a survey data of emerging market firms which is currently not available. Third, it would be a noteworthy extension to include government fiscal policy and analyze welfare gains. Monetary policies in several emerging markets are relatively new and have limits, and fiscal policies can target specific targets. Thus, introducing fiscal policies into this framework would be more appropriate. Exploring how this fiscal policy can be useful in the business cycle with the endogenous productivity mechanism would be worthwhile. Gertler and Kiyotaki (2010), Gertler et al. (2012), and Akinici and Queralto (2016) examine how government intervention could mitigate the powerful impact of the financial crises. Analyzing this topic with the endogenous TFP mechanism might provide another policy implication.

In summation, the results stress the effects of demand factors on the supply side. This is important since it can explain the persistent downturns after financial crises and provide an insight into exogenous technological shocks.

References

Aguiar, M. and G. Gopinath (2006). "Emerging market fluctuations: The role of interest rates and productivity shocks." Current Account and External Financing.

Aguiar, M. and G. Gopinath (2007). "Emerging market business cycles: The cycle is the trend." Journal of Political Economy 115(1): 69-102.

Anzoategui, D., et al. (2019). "Endogenous technology adoption and R&D as sources of business cycle persistence." American Economic Journal: Macroeconomics 11(3): 67-110.

Aw, B. Y., et al. (2011). "R&D investment, exporting, and productivity dynamics." American Economic Review 101(4): 1312-1344.

Basu, S. and M. S. Kimball (1997). "Cyclical productivity with unobserved input variation." National Bureau of Economic Research.

Benigno, G. and L. Fornaro (2017). "Stagnation traps." The Review of Economic Studies 85(3): 1425-1470.

Boileau, M. and M. Normandin (2017). "The price of imported capital and consumption fluctuations in emerging economies." Journal of International Economics 108: 67-81.

Boz, E., et al. (2011). "Emerging market business cycles: Learning about the trend." Journal of Monetary Economics 58(6-8): 616-631.

Brauer, M., et al. (2016). "The Next Generation of the Penn World Table." World Bank Seattle.

Cerra, V. and S. C. Saxena (2008). "Growth dynamics: the myth of economic recovery." American Economic Review 98(1): 439-457.

Chang, R. (2015). “Commodity Price Fluctuations and Monetary Policy in Small Open Economies.” Commodity Prices and Macroeconomic Policy 22: 019-050.

Chang, R. and A. Fernández (2013). “On the sources of aggregate fluctuations in emerging economies.” International Economic Review 54(4): 1265-1293.

Christiano, L. J., et al. (1999). “Monetary policy shocks: What have we learned and to what end?” Handbook of macroeconomics 1: 65-148.

Comin, D. and M. Gertler (2006). “Medium-term business cycles.” American Economic Review 96(3): 523-551.

Crépon, B., et al. (1998). “Research, Innovation And Productivity: An Econometric Analysis At The Firm Level.” Economics of Innovation and new Technology 7(2): 115-158.

Fernández, A. and A. Gulan (2015). “Interest rates, leverage, and business cycles in emerging economies: The role of financial frictions.” American Economic Journal: Macroeconomics 7(3): 153-188.

Fernández-Villaverde, J., et al. (2011). “Risk Matters: The Real Effects of Volatility Shocks.” American Economic Review 101(6): 2530-2561.

Garcia-Cicco, J., et al. (2010). “Real business cycles in emerging countries?” American Economic Review 100(5): 2510-2531.

Greenwood, J., et al. (1988). “Investment, capacity utilization, and the real business cycle.” The American Economic Review: 402-417.

Guellec, D. and B. v. P. De La Potterie (2002). “R&D and productivity growth.” OECD Economic studies 2001(2): 103-126.

Hanson, G. H. (2010). “Why isn’t Mexico rich?” Journal of Economic Literature 48(4): 987-1004.

Herbst, E. P. and F. Schorfheide (2015). "Bayesian estimation of DSGE models." Princeton University Press.

Jaimovich, N. and S. Rebelo (2009). "Can news about the future drive the business cycle?" American Economic Review 99(4): 1097-1118.

Justiniano, A., et al. (2011). "Investment shocks and the relative price of investment." Review of Economic Dynamics 14(1): 102-121.

Kortum, S. and J. Lerner (2001). "Does venture capital spur innovation? Innovatorial inputs and outcomes: New studies of innovatorship in the United States." Emerald Group Publishing Limited: 1-44.

Kortum, S. S. and J. Lerner (2000). "Assessing the impact of venture capital on innovation." RAND Journal of Economics, Winter.

Laeven, L. and F. Valencia (2013). "Systemic banking crises database." IMF Economic Review 61(2): 225-270.

Mendoza, E. G. (1991). "Real business cycles in a small open economy." The American Economic Review: 797-818.

Neumeyer, P. A. and F. Perri (2005). "Business cycles in emerging economies: the role of interest rates." Journal of Monetary Economics 52(2): 345-380.

Oviedo, P. M. (2005). "World interest rate, business cycles, and financial intermediation in small open economies." Staff General Research Papers Archive 12360, Iowa State University, Department of Economics.

Queralto, A. (2019). "A model of slow recoveries from financial crises." Journal of Monetary Economics.

Reinhart, C. M. and V. R. Reinhart (2010). "After the fall." National Bureau of Economic Research.

Reinhart, C. M. and K. S. Rogoff (2009). "This time is different: Eight centuries of financial folly." Princeton university press.

Romer, P. M. (1990). "Endogenous technological change." Journal of Political Economy 98(5, Part 2): S71-S102.

Romer and Romer (1989). "Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz." National Bureau of Economic Research.

Schmitt-Grohé, S. and M. Uribe (2003). "Closing small open economy models." Journal of International Economics 61(1): 163-185.

University of Groningen and University of California, Davis, "Total Factor Productivity at Constant National Prices for Mexico."

Uribe, M. and V. Z. Yue (2006). "Country spreads and emerging countries: Who drives whom?" Journal of International Economics 69(1): 6-36.

Appendix

Qualitative measures

This paper borrows the qualitative measures of financial crises from Laeven and Valencia (2013). They define a banking crisis with (1) significant signs of financial distress in the banking system and (2) significant banking policy intervention measures in response to significant losses in the banking system. They also define a currency crisis as an at least 30 percent nominal depreciation of the local currency relative to the U.S. dollar that is also at least ten percentage points higher than the rate of depreciation in the year before. Then this paper aggregates these two crises and defines it as financial crises.

On the other hand, the measures for the other recession were constructed as in OECD-based Recession Indicators. Real GDP was log-detrended. Then this paper selects the other recession periods based on this log-detrended data not to overlap with the documented financial crises.

Model specification

- The adjustment cost function, $s(\cdot)$, is increasing and concave with $s(\cdot) = s'(\cdot) = 0$ and $s''(\cdot) > 0$ as in the literature.
- The success probability of adoption: $\lambda(\bullet) = \kappa_\lambda(\bullet)^{\rho_\lambda}$, an increasing and concave function. κ_λ and $0 < \rho_\lambda < 1$ are constants.
- The depreciation rate: $\delta(U_t) = \delta - d_1/(1+\omega) + d_1 U_t^{1+\omega}/(1+\omega)$, an increasing and convex function.
- The working capital restrictions: $\omega_t^r = \left(1 + \frac{\theta_w(R_t - 1)}{R_t}\right) w_{ut}$
- The production function: $Y_t \simeq \overline{Y_t}$ since $\int_0^{A_t} K_t^j dj = K_t$ and $\int_0^{A_t} L_t^j dj = L_t$

국문초록

이 논문은 개발도상국에서 금융 위기의 여파가 장기간 지속되는 현상을 분석하기 위해 Research & Development (R&D), 기술 채택, 그리고 생산성의 역할을 탐구한다. 우선 통계적 분석은 금융 위기가 다른 위기에 비해 R&D, 생산성, 그리고 생산물을 더 크고 지속적으로 감소시킴을 보여준다. 이와 같은 생산성 관련 변수들의 움직임과 생산물의 움직임은 데이터에 기반한 거시 경제 모형을 통해 연결되었다. 모형은 국제 실물 경기변동 이론 (International Real Business Cycle model; IRBC model) 위에서 내생적인 생산성을 가지도록 설계되었다. 구체적으로 R&D와 기술채택은 개발도상국의 경기 순환에서 중요하다고 판단되는 외생적 충격들에 영향을 받는다고 가정되었다. 위험 프리미엄의 증가는 여러 종류의 수요들을 줄이기 때문에, R&D와 기술채택 분야가 비활성화되고 생산성과 생산물의 성장은 그렇지 않을 경우보다 더욱 심하게 감소하게 된다. 주요 결과에 따르면 금융 위기는 수요 변수들에 영향을 미치는데, 이 여파가 내생적인 생산성 메커니즘을 통해 경제에 더 지속적이고 강력한 영향을 가지게 된다. 또한 일반적인 관점에서 이 모형은 거시 경제 변수의 변화에 따른 생산성 변화에 대한 통찰력을 제공한다. 이는 개발도상국의 경기순환에서 중요한 요소임에도 불구하고 잘 연구되지 않았던 부분이다. 그럼으로써 이 모형은 선행연구에서 임의로 주어졌던 이자율과 생산성 사이의 관계에 대한 이론적 근거를 부여한다.

주요어 : 금융위기, R&D, 기술채택, 경기순환
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Persistent financial crises in emerging economies:

with endogenous R&D and adoption

개발도상국에서 장기간 지속되는 금융위기에 대한 분석

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김 철 환

Abstract

Persistent financial crises in emerging economies:

with endogenous R&D and adoption

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This thesis explores the role of R&D, adoption, and productivity to explain why financial crises in emerging markets have more persistent and severe effects on output than other crises. The empirical analysis presents evidence that financial crises cripple R&D, productivity, and output more severely and persistently than other crises. In order to connect these crippled factors to output, a quantitative macroeconomic model was constructed on an international real business cycle model with endogenous R&D, adoption, and productivity. R&D and adoption activities were assumed to be subject to exogenous shocks, or major sources of emerging market business cycles. Since the rise of risk premium discourages the demand factors, R&D and adoption sectors suffer, and the growth of productivity and output are more severely deterred than otherwise. In conclusion, the main findings indicate that the endogenous total factor productivity mechanism amplifies the impact of financial crises on the demand factors to be more persistent and severe. More generally, this model analysis provides an insight into the relationship between exogenous technological changes and the changes of macroeconomic variables, which, despite its importance in the business cycles, has been under-researched. Thus, this model assigns a proper mechanism for the ad hoc relationship between an interest rate and productivity in the literature.

keywords : Financial crises, R&D, adoption, Business cycle
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Ⅰ. Introduction

The Global Financial Crisis was a reminder of the stylized fact that financial crises are followed by persistent downturns, whether they occur in advanced or developing countries. Reinhart and Rogoff (2009), Reinhart and Reinhart (2010), and Cerra and Saxena (2008) well document the slow recoveries from financial crises.

After this crisis, extensive literature emerged to explain these persistent downturns in advanced countries in two ways. A number of researchers emphasize the persistent fall of demand factors (Christiano et al. 2015). Some examine the deleveraging process while others analyze the constraints on macroeconomic policies. Though these demand factors must have played a significant role, they alone cannot explain the slow recoveries to the initial trend. Thus, several authors explore supply factors. Hall (2015) investigate the decrease of the capital stock while Reifschneider et al. (2015) add the drop in productivity to it. Reifschneider et al. (2015) conjecture that the endogenous decline in productivity-enhancing investment led to the drop in productivity. On the other hand, Garcia-Macia (2015) analyzes the misallocation of capital, and Decker et al. (2017) examine business dynamism as a source of the decline in productivity.

Indeed, the declines in productivity were observed multiple times worldwide in financial crises (Queralto, 2019; Huber 2018). Thus, this paper connects the decrease in productivity to persistent downturns after financial crises in emerging markets, assuming the decline of productivity could be endogenous. In particular, it focuses on productivity-enhancing investments (Comin and Gertler, 2006; Reifschneider, 2015; Anzoategui et al., 2019; Queralto, 2019). The endogenous drop in the investment from the crises could result in the subsequent decline of productivity.

However, most of the literature on emerging market business cycles has stressed financial frictions and exogenous technological shocks. Schimitt-Grohe and Uribe (2002) comprehensively examine small open economy models. Aguiar and Gopinath (2007) pioneer this literature by introducing a stochastic permanent technology process. But note that exogenous permanent technology shocks remain unknown. Neumeyer and Perri (2005), Fernandez-Villaverde et al. (2011), and

Chang and Fernandez (2013) accentuate the role of interest rates in business cycles. Lastly, Aguiar and Gopinath (2008) imply that this trend growth could be the result of frictions, such as financial frictions. According to Garcia-Cicco et al. (2010) and Fernandez and Gulan (2015), financial frictions could be important in explaining the business cycle of emerging economies.[1] However, this might not be the case with other channels that can replace the role of financial frictions.

Thus, this paper analyzes these crises in emerging markets (1) to verify whether R&D, adoption, and productivity are the source of the prolonged downturns as in advanced countries; and (2) to investigate the exogenous technological shocks.

Besides, many previous studies of emerging market business cycles emphasize the relationship between productivity and an interest rate for replicating emerging market business cycles. But they provide little justification for this relationship (Oviedo, 2005; Aguiar and Gopinath, 2008; Chang and Fernández, 2013). However, this is an evident relationship among R&D, adoption, and productivity. The change in macroeconomic variables will influence the decision of business sectors to invest in R&D and adoption. The change in R&D and adoption, in return, will inevitably affect productivity and output. Hence, this paper introduces these channels to assign a proper mechanism based on the literature of R&D investment (Crépon et al., 1998).

For these reasons, R&D, adoption, and productivity were assumed to be endogenous to answer these initiatives. Accordingly, this paper conducts an empirical analysis and constructs a quantitative macroeconomic model accordingly. Since the small open economy literature has been based on developing countries in Latin America, this paper focuses on them to confirm whether the new mechanism is applicable. The method of Romer and Romer (1989) was applied in the empirical analysis to identify the different effect of financial crises on R&D, adoption, and productivity. The data of Latin American countries were used here as the literature of emerging market business cycles.

As a result, the key findings indicate that financial crises have more persistent and severe impacts on total hours, labor productivity, and output. Furthermore, the

1) In addition, many other studies have explored the other possible sources of the business cycle, such as commodity demand or price (Fernandez et al., 2018; Drechsel and Tenreyro, 2018).

result suggests qualitative differences between the impact of financial crises and the other recessions. TFP, business R&D investment, and the number of patents showed more significant and permanent declines after financial crises. This implies that the differences are not from the size (quantity) of the shock, but from the quality.

Based on the empirical analysis results, a quantitative macroeconomic model was constructed to connect the decline in R&D, adoption, and productivity to the decrease in output. The whole model was built on an IRBC model with the endogenous TFP mechanism. Essentially, this model follows several seminal works in the business cycle of emerging countries. The basic structure of the small open economy model was employed with shocks that are widely known to be the crucial parts of the business cycle. Specifically, this paper focuses on risk premium shocks because they are crucial variables in the emerging market business cycles (Neumeyer and Perri, 2005; Fernandez-Villaverde et al., 2011; Chang and Fernandez, 2013). They were also used to represent financial shocks, especially in financial crises (Anzoategui et al., 2019; Queralto, 2019). Then financial frictions were introduced here to reflect the risk premium and debt burden. They were necessary due to their role in emerging markets and the stationarity of the model. Schimitt-Grohe and Uribe (2002) prove that such a condition is needed to guarantee the stationarity of the model. Aguiar and Gopinath (2008), Garcia-Cicco et al. (2010), and Fernandez and Gulan (2015) stress the importance of financial frictions.

Most importantly, the endogenous TFP mechanism was introduced into this model. The endogenous productivity mechanism implies that R&D, adoption, and TFP are no longer exogenous as in the IRBC literature. They are explicitly included in the model. This integration of the endogenous TFP mechanism and an IRBC model is the key feature that distinguishes this model from the literature. Especially an exogenous risk premium shock was included as the variable of focus to affect demand factors which, in return, influence R&D and adoption sectors and productivity. This is the part where this new mechanism magnifies the size and persistence of financial crises. In the following model, five types of agents exist: households, capital producers, researchers and adopters, and goods producers. Households maximize their utilities with the money borrowed from the world, labor income, the profit from goods producers, and more. Capital producers create

capital goods from final goods and sell it to households who rent it to intermediate-goods firms. TFP is created through two productivity-enhancing investments (Comin and Gertler, 2006): (1) R&D: the creation of new technologies and (2) Adoption: the conversion of these new technologies into usable ones. These two processes use skilled labor as an input. In turn, intermediate-goods producers who have access to the usable technology combine this with unskilled labor and utilized capital to produce their goods. In the end, a homogeneous final output is produced with an aggregate of intermediate goods. Note that the model with an exogenous TFP mechanism was also included to compare the result. Lastly, key parameters were borrowed from the IRBC literature.

Basically, this mechanism is based on the seminal literature of the endogenous TFP mechanism. Schmookler (1966) and Shleifer (1986) analyze the effect of aggregated demand on innovation. Romer (1990) and Comin and Gertler (2006) endogenize TFP. Romer (1990) uses the research sector, and later, Comin and Gertler (2006) add the adoption process to the research sector to reflect realistic lags in the creation of usable technology. Since then, many developments followed these seminal works. Comin et al. (2009) estimate a version of Comin and Gertler (2006), and Comin et al. (2014) propose a two-country framework between developing countries and advanced countries. Anzoategui et al. (2019), Queralto (2019), Guerron-Quintana and Jinnai (2014), and Garcia-Macia (2017) suggest endogenous growth mechanisms to explain the persistent financial crises. Comin and Gertler (2006), Anzoategui et al. (2019), Moran and Queralto (2018), and Bianchi, Kung, and Morales (2019) focus on this mechanism in advanced countries while this paper analyzes it in emerging countries.[2] This paper also differs by using business R&D expenditure and introducing financial frictions.[3] Though Ates and Saffie (2016) and Queralto (2019) examine this mechanism in emerging markets, they mainly stress borrowing frictions in banking crises and construct these frictions. However, this paper employs simple financial frictions as in the IRBC model and instead includes both banking crises and currency crises as financial crises.

2) Bianchi, Kung, and Morales (2019) construct a macroeconomic model with endogenous growth and estimate it with R&D data for the first time. However, the model of this paper focuses on developing countries and is more explicit. For a more detailed discussion, see Anzoategui et al. (2019).

3) Though Anzoategui et al. (2019) use business R&D expenditure, it does not have financial frictions.

Furthermore, this paper investigates adoption as well, which is consistent with the literature. Midrigan and Xu (2014) use emerging market firm-level data and empirically show that financial frictions harm productivity over the long run because they distort firm entry and technology adoption. According to them, it is much greater than misallocation across producers. However, unlike the previous study, this paper examines medium-run dynamics after financial crises and develops a quantitative model with macroeconomic variables. Also, the sample of interest is different. While Queralto (2019) examines the bigger cross country data for empirical analysis and South Korea for model analysis, this paper concentrates on Latin American countries because the IRBC literature is mostly based on them. In addition, this paper newly analyzes patent. Lastly, since the endogenous mechanism has its burden of complexity, this model abstracted from monetary policy and wage and price rigidities, unlike the literature (Anzoategui et al., 2019). Therefore, all the variables are in real terms as in the small open economy model literature.

On the other hand, note that Gertler et al. (2007), Mendoza (2010), and Mendoza and Yue (2012) examine financial crises in developing countries with quantitative frameworks. Some of them and others also explain the observed decline in TFP, capacity utilization, and more during financial crises.[4] But this paper accounts for how medium-run TFP declines and how they lead to persistent downturns. It also differentiates this paper from other quantitative analyses of financial crises in emerging markets. Most importantly, this paper is unique in that it examines R&D and adoption as a channel for such a phenomenon, though it can be seen as complementary to the past research.

In conclusion, this model analysis provides answers to the initiatives. As the risk premium rises in financial crises, the demands for consumption, capital investment, unskilled labor, and productivity-enhancing investments fall. Then the endogenous productivity channel amplifies financial crises more severe and persistent than other crises. This is consistent with the results of the empirical analysis. In contrast, the model with the exogenous productivity mechanism cannot explain the persistent downturns of productivity and output after financial crises. These results showed qualitative differences to the same size of the shock.

4) See Gopinath and Neiman (2014), Benjamin and Meza (2009), Meza and Quintin (2007), Kehoe and Ruhi (2009), Pratap and Urrutia (2012), and Aoki et al. (2009).

Moreover, note that both analyses are related to the IRBC literature that emphasizes large movements in exogenous productivity in emerging market business cycles. This paper shows how exogenous technology shocks can be endogenized and investigated. Thus, it provides a proper mechanism for the relationship between macroeconomic variables and productivity (Oviedo, 2005; Aguiar and Gopinath, 2008; Chang and Fernández, 2013).

The paper is organized as follows. Section I provides an introduction, and Section II presents the empirical analysis that shows qualitatively different behaviors of R&D and productivity to financial crises. Section III describes a quantitative macroeconomic model that connects the decrease in R&D, adoption, and productivity to persistent downturns after the crises, and Section IV presents an analysis of the model. Lastly, Section V provides concluding remarks.

Ⅱ. Empirical Analysis

2.1. Empirical Methodology

Empirically, the method of Romer and Romer (1989) was used here to identify the different impacts of financial crises and other crises on several macroeconomic variables.[5] The variables are real GDP, total hours, labor productivity, TFP, business R&D investment, and the number of utility patents. This method was used because the dynamic effects of a particular event can be estimated. In the following model, the changes in macroeconomic variables over time are captured as they are influenced by a particular type of crises. This method has an advantage in such event analysis (Romer and Romer, 1989; Cerra and Saxena, 2008; Queralto, 2019). Cerra and Saxena (2008) use a similar method to compare the impacts of financial rises relative to political crises while Queralto (2019) examines the impacts of financial crises on productivity-related variables. However, this paper differs from Cerra and Saxena (2008) because this analysis compares the impacts of financial crises and those of other economic crises. Also, there are differences between Queralto (2019) and this paper because this paper uses only the sample of developing countries in Latin America and newly analyzes patents.

5) Romer and Romer (1989) examine the shocks of monetary policies on the economy with industrial production and unemployment.

Note that this paper focuses on developing countries in Latin America, as the small open economy model literature did, to verify whether the new mechanism is applicable.

In particular, a univariate autoregressive model was estimated to account for serial correlation in growth rates.[6] Also, growth rates were used due to the nonstationarity of output (Charles Nelson and Charles Plosser, 1982).[7] The equation for an economy i (i= 1, ..., 5) is as follows:

$$x_{i,t} = \alpha_i + \sum_{j=1}^{J} \beta_j x_{i,t-j} + \sum_{k=0}^{K} \gamma_k D_{i,t-k} + \epsilon_{i,t} \qquad (1)$$

where $x_{i,t}$ is the percentage growth rate of a macroeconomic variable, α_i is a country fixed effect, and $D_{i,t}$ is a dummy variable or a qualitative indicator of economic crises. Since F-tests indicated the presence of country fixed effects, they were included to control for the country-specific factor that is not reflected in the model but affects the variable of interest.[8] Then the lags J and K were included to reflect the current and lagged impacts, and they were selected to be 1 and 5 from Akaike Infomation Criterion and Bayesian Information Criterion. However, the result was robust to other selection of lags.

Accordingly, impulse responses were estimated to the event of a particular economic crisis with cross country panel data, and the group averages of the responses were provided with a one standard error band drawn from a thousand Monte Carlo simulations. Thus, it shows how a particular type of economic crises can affect macroeconomic variables statistically.

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6) Levin-Lin-Chu panel unit roots tests were conducted. The lags were selected from Akaike Information Criterion with at most ten lags. The test suggested the presence of unit roots in real GDP, TFP, and labor productivity.

7) To facilitate the interpretation between variables, other stationary variables were also changed into growth rates.

8) Though there are correlations between the country fixed effects and the lagged dependent variables, it is likely to be small with low persistence (Stephen Nickell, 1981; Ruth Judson and Ann Owen, 1999).

2.2. Data

The estimation used balanced cross-country panel data from 1951 to 2017. Only the data on business R&D investment and the number of patents are from 1996 to 2017 and from 1992 to 2017, respectively. The country included several Latin American countries such as Argentina, Brazil, Chile, Colombia, and Mexico. The data used are real GDP, total hours, TFP, labor productivity, business R&D investment, the number of utility patents granted, and the qualitative measure of financial crises and the other recessions. Here total hours were constructed by multiplying average working hours with the number of employed people. Labor productivity was built on real GDP by dividing it with total hours. The qualitative indicator of the other recessions was constructed in a way similar to setting OECD based Recession Indicators.[9)]

Real GDP, TFP, average working hours, and the number of employed people were obtained from Feenstra et al. (2015). Business R&D investment from the UNESCO Institute for Statistics. The number of patents from the United States Patent and Trademark Office (USPTO). The qualitative indicator of financial crises from Laeven and Valencia (2013). Only business R&D investment was selected based on the source of the investment because it is the focus of the whole paper. The number of patents was assigned to each country based on the first inventor's address as in the literature. Also, only utility patents were used because they are known as patents for inventions. Laeven and Valencia (2013) document baking crises and currency crises worldwide from 1970 to 2016. The qualitative measure of financial crises was constructed as the sum of these two types of crises.

These variables were included as the main variables of interest. Real GDP was included since it is the best indicator of economic activities. Labor productivity, TFP, business R&D investment, and the number of patents were investigated because they are the main topic of this paper. The number of patents is the indicator for the input as well as the output because the patents are not only the result of R&D activities but also the resource of productivity (Lee, 2013). Sometimes several patents become obsolete with few citations. Here real GDP was decomposed into labor productivity and total hours, and they were used to

9) See Appendix for further details.

examine the impact of financial crises and the other recessions following the equation (Queralto, 2019):

$$\log Y_{i,t} = \log Y_{i,t}/N_{i,t} + \log N_{i,t} \tag{2}$$

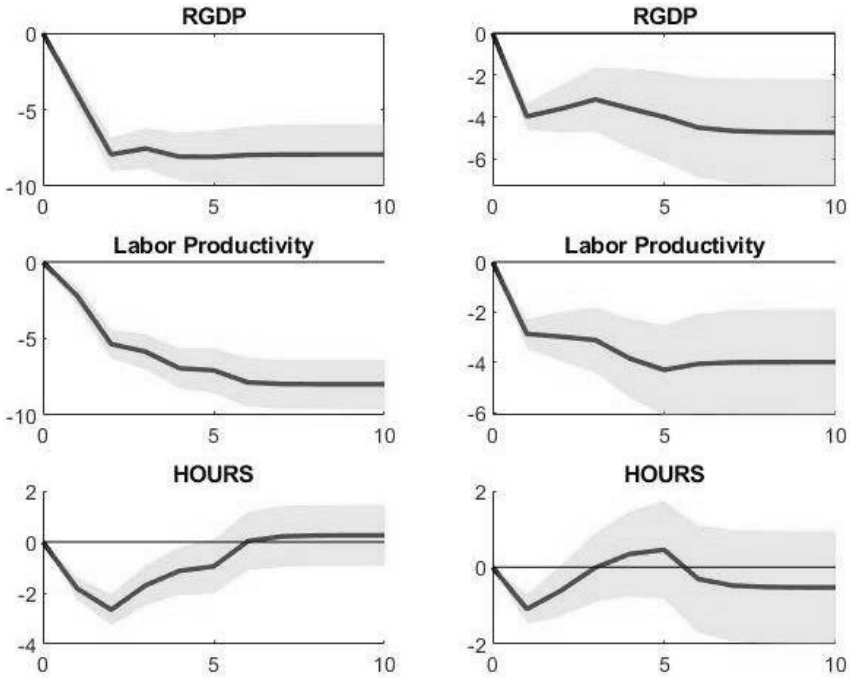
However, business R&D investment and the number of patents were employed to identify qualitative differences between financial crises and the other recessions. Lastly, note that all the data are in real terms. Thus, the impulse responses of every variable are set to 100 in period 0 (benchmark), and the changes are in terms of percentage.

2.3. Estimation Results

Figure 1 reports the results, the impulse responses of macroeconomic variables – output, total hours, and labor productivity – to the event of financial crises or the other recessions. The left column shows the responses to financial crises while the right column provides the responses to the other recessions. The responding variable names are denoted at the top of each graph, and the responses were estimated over ten years.

The first row of Figure 1 indicates that the output decreases more deeply and persistently in financial crises than the other recessions. Real GDP in financial crises decreases by approximately 8% after four years while real GDP in the others declines by around 4% after five years. The declines of real GDP in both cases are significant and persistent as in the literature (Cerra and Saxena, 2008; Queralto, 2019). Also, the second and third rows imply that the responses of labor productivity and total hours are more severe and persistent in financial crises. Labor productivity in financial crises decreases by approximately 8% after six years while that in the other recessions declines by around 4% after five years. The losses of labor productivity in both crises are not only significant but also long-lasting. Total hours in financial crises decline by 3% after two years, but the losses become insignificant after five years. However, total hours in the other recessions decrease by 1% in a year, but the decline becomes insignificant after two years.

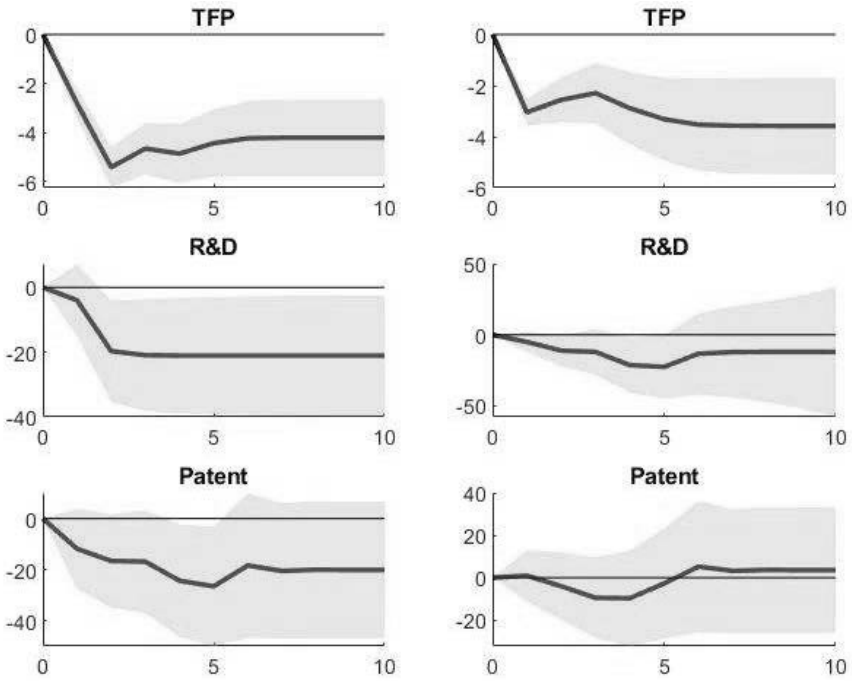
Figure 1. Impulse responses of real GDP and its components



In summation, financial crises have more persistent and severe impacts on total hours and labor productivity. Therefore, output decreases more permanently and severely in financial crises. This is well indicated by the decomposition of output, eq (2). The interesting point is that the response of labor productivity accounts for the response of output better than that of total hours.

However, these differences might have originated from the size of the shocks. In other words, the negative shocks might have been much bigger in financial crises, and the size difference could have led to such different results. For this reason, it was necessary to identify qualitative differences that, unlike the other recessions, financial crises, in particular, devastate R&D and productivity. Thus, the same methodology was applied to estimate the responses of TFP, business R&D, and the number of patents. Here TFP was used instead of labor productivity because it is relatively more exogenous than the other. Figure 2 summarizes the result as before with each column showing the responses to financial crises and the other recessions, respectively.

Figure 2. Impulse response of TFP, R&D investment, and the number of patents



The first row of Figure 2 implies that the decline of TFP in financial crises is bigger. TFP in financial crises decreases by around 5% after two years while that in the other recessions reduces by approximately 4% after five years. The losses in both crises are permanent and significant. The second row and the third row also show that business R&D investment and the number of patents decrease more permanently and deeply in financial crises. Business R&D investment in financial crises diminishes by approximately 21% after four years, and the losses are significant for the whole period except for the first year. However, the investment in the other recessions decreases by around 21% after four years, but the responses are significant only for the second, fourth, and fifth year. Moreover, the patent number in financial crises declines by approximately 25% after four years, and the decline is significant for the fourth and fifth years. The patent number in the other recessions reduces by around 10% after three years, but the whole response is insignificant.

To summarize, the result seems consistent with the literature (Cerra and

Saxena, 2008; Queralto, 2019). Most importantly, the responses of TFP, business R&D investment, and the patent number suggest that unlike the other recessions, financial crises paralyze R&D and productivity. Accordingly, a quantitative macroeconomic model was built on this finding to connect the dots - to link the decline of R&D, productivity, and output.

Ⅲ. Model

3.1. The model with endogenous productivity

3.1.1. Households

There is a continuum of measure one of representative households, and each household h has a unit measure of members. It consumes, saves and rents capital to intermediate-goods firms, and borrows from foreign investors.

Moreover, the household's problem has unique features when compared to that of the standard model. First, there is a slight difference in the structure of preference from the IRBC literature. The term, X_t, in the disutility of labor depends on the aggregate technological level, A_t, as follows: $X_t = A_t^{\gamma} X_{t-1}^{1-\gamma}$, $0 < \gamma \leq 1$. If $X_t = 1$ (a constant) as Greenwood et al. (1988) (GHH preference), this could be a problem because it implies a trend growth in working hours though there is a physical limit. Besides, X_t could be used to follow a balanced growth path. Thus, the preference of Jaimovich and Rebelo (2009) was used here. Also, they showed that with small γ, this preference is consistent with the GHH preference. Variations in A_t will have a short-run wealth effect on labor supply or a small medium-run impact on labor supply.[10] Therefore, a rise in an interest rate does not lead to an increase in labor supply, which discourages counter-factual booms in employment and output.

Second, although the household h is a monopolistically competitive supplier of labor as in standard set-ups, there exist two types of labor. This distinction was made to consider innovation and adoption effort in the model as illustrated in

10) See Jaimovich and Rebelo (2009) for more information on this type of preference.

Anzoategui et al. (2019): unskilled labor, L_{ut}, for the production of intermediate-goods; and skilled labor, L_{st}, for R&D or adoption by innovators and adopters. As in the standard models, monopolistically competitive employment agencies aggregate each type of labor into a homogenous labor input:

$$L_{it} = \left(\int_0^1 \left(L_{it}^h\right)^{\frac{1}{\mu_{ut}}} dh \right)^{\mu_{ut}}, \ i = u, s \tag{3}$$

where μ_{wt} is the elasticity of substitution across labor types and follows an exogenous autoregressive process of order 1 (AR (1) process):

$$\log(\mu_{wt}) = (1-\rho_{\mu_w})\mu_w + \rho_{\mu_w}\log(\mu_{wt-1}) + \sigma_{\mu_w}\epsilon_t^{\mu_w}, \ \epsilon_t^{\mu_w} \sim \textbf{\textit{iid}} \tag{4}$$

From employment agencies' cost minimization, the demand for L_{it}^h is given by

$$L_{it}^h = (w_{i[t}/w_t)^{\mu_{ut}/(\mu_{ut}-1)} L_{it} \ \textbf{where} \ w_{it} = \left(\int_0^1 (w_{it})^{1/(1-\mu_{ut})} dh\right)^{1-\mu_{ut}}, \tag{5}$$

i = u, s and w_{it} is the real wage of labor type i.[11]

Let C_t be consumption, B_t total domestic debt held by foreign investors, Π_t profits from the ownership of firms, K_t capital stock, D_t the rental rate of capital, and Q_t the price of capital. Then the households make decisions:

$$\max_{C_{t+\tau}, B_{t+\tau}, L_{ut+\tau}, L_{st+\tau}, K_{t+1+\tau}} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left\{ \frac{\left(C_{t+\tau} - \frac{\theta_1}{w_1} X_{t+\tau} \left(L_{ut+\tau}\right)^{w_1} - \frac{\theta_2}{w_1} X_{t+\tau} \left(L_{st+\tau}\right)^{w_1} \right)^{1-\sigma} - 1}{1-\sigma} \right\} \tag{6}$$

$$\textbf{subject to} \ B_t + w_{ut}L_{ut} + w_{st}L_{st} + \Pi_t + R_{kt}Q_{t-1}K_t = Q_t K_{t+1} + R_{t-1}B_{t-1} + C_t \tag{7}$$

where the rate of return, $R_{kt} \equiv (D_t + Q_t)/Q_{t-1}$ and the household's stochastic discount factor, $\Lambda_{t,t+1} \equiv \beta u'(C_{t+1})/u'(C_t)$. The first-order conditions for B_t and K_{t+1} are, respectively:

$$E_t \Lambda_{t,t+1} R_t = 1 \tag{8}$$

11) From this point, the superscript h will often be omitted since each agent makes the symmetric decision in the equilibrium.

$$E_t \Lambda_{t,t+1} R_{kt+1} = 1 \tag{9}$$

The interest rate, R_t, consists of the steady-state world interest rate, R, borrowing frictions, $\overline{\Psi}\{\exp(B_t/Y_t - \overline{d}) - 1\}$, and an exogenous risk premium, μ_t^r. The frictions or the risk premium parts (8) consist of the ratio of debt to output, B_t/Y_t, and a random risk premium shock, μ_t^r. This mechanism is introduced to include simple financial frictions and to ensure stationary dynamics as in the small open economy model literature (Schimitt-Grohe and Uribe, 2002). The random risk premium disturbance, μ_t^r, is assumed to follow an AR(1) process:

$$R_t = R + \overline{\Psi}\{\exp(B_t/Y_t - \overline{d}) - 1\} + \exp(\mu_t^r) - 1 \tag{10}$$

$$\text{where } \mu_t^r = \rho_r \mu_{t-1}^r + \sigma_r \epsilon_t^r,\ \epsilon_t^r \text{~iid} \tag{11}$$

3.1.2. Capital Producers

Capital producers make new capital goods, I_t, using final goods, and they sell these goods to households. Let p_{kt} be the relative price of making new capital out of new capital goods, the logarithm of which is assumed to follow an AR(1) process without a constant term. The investment adjustment costs, $s(\cdot)$ were assumed to include realistic lags in the evolution of capitals. Then, capital producers' optimization problem is:

$$\max_{I_t} E_t \sum_{\tau=0}^{\infty} \Lambda_{t,\ t+\tau} \left[Q_{t+\tau} I_{t+\tau} - \left\{ 1 + s\left(\frac{I_{t+\tau}}{I_{t+\tau-1}} \right) \right\} I_{t+\tau} p_{kt+\tau} \right]$$

The first-order condition provides the relationship between the ratio of Q_t to p_{kt} and investment. The ratio on the left-hand side can be interpreted as Tobin's Q:[12)]

$$\begin{aligned} \frac{Q_t}{p_{kt}} = 1 + s\left(\frac{I_t}{(1+\gamma_y) I_{t-1}} \right) + \frac{I_t}{(1+\gamma_y) I_{t-1}} s'\left(\frac{I_t}{(1+\gamma_y) I_{t-1}} \right) \\ - E_t \Lambda_{t,\ t+1} \left(\frac{I_{t+1}}{(1+\gamma_y) I_t} \right)^2 s'\left(\frac{I_{t+1}}{(1+\gamma_y) I_t} \right) p_{kt+1} (1+\gamma_y) / p_{kt} \Lambda_{t,t} \end{aligned} \tag{12}$$

12) The ratio between the market value of a physical asset and its replacement value.

The law of motion for capital is

$$K_{t+1} = I_t + (1-\delta(U_t))K_t \tag{13}$$

3.1.3. Production Sector

To introduce the endogenous productivity mechanism, this model constructs the production sector in a way similar to that of Comin and Gertler (2006) and Anzoategui et al. (2019). Two types of mopolistically competitive firms exist in goods production; intermediate-goods producers produce materials for final-goods producers. Final-goods production consists of a continuum of producers whose measure is unity, and each of the firms i produces a differentiated output, Y_t^i, by using a unit of intermediate-goods composite, Y_{mt}^i, as input: $Y_t^i = Y_{mt}^i$

Then, a final good composite is constructed as the aggregate of the differentiated final goods:

$$Y_t = \left(\int_0^1 \left(Y_t^i\right)^{\frac{1}{\mu_t}} di\right)^{\mu_t}, \ \mu_t > 1 \tag{14}$$

where $\log(\mu_t)$ follows an AR(1) process:

$$\log(\mu_t) = (1-\rho_\mu)\mu + \rho_\mu \log(\mu_{t-1}) + \sigma_\mu \epsilon_t^\mu, \quad \epsilon_t^\mu \sim iid \tag{15}$$

However, this paper abstracts from staggered price or wage setting to make all the prices perfectly flexible as in the small open economy model literature because the endogenous productivity mechanism has its burden on complexity. Note that it does not obscure the critical results of this paper. Thus,

$$MC_t \mu_t = 1, \ \ MC_t = p_{mt} / A_t^{v-1} \tag{16}$$

where MC_t is the marginal cost of final goods firms, μ_t price markup, and p_{mt} the relative price of the intermediate-goods composite.

On the other hand, there is a continuum of competitive intermediate-goods firms, with the measure A_t, which makes a differentiated product, respectively. A_t is the aggregate of technologies adopted or productivity. This variable will be endogenously predetermined by R&D and adoption sectors in the following section.

The intermediate-goods composite is the aggregate of individual intermediate goods, Y_{mt}^{j} :

$$Y_{mt} = (\int_{0}^{A_t} (Y_{mt}^{j})^{1/\upsilon})^{\upsilon}, \ \textbf{\textit{with}} \ \upsilon > 1 \tag{17}$$

Let U_t^j be the degree to which the capital is used by firm *j*, K_t^j be the stock of capital firm *j* employs, and L_{ut}^j the stock of unskilled labor firm *j* employs. Anzoategui et al. (2019) argue that one can avoid ascribing all high-frequency variation in the Solow residual to endogenous productivity by introducing capital utilization intensity, U_t^j. Then each intermediate goods firm *j* uses capital services $U_t^j K_t^j$ and unskilled labor L_{ut}^j to produce intermediate goods Y_{mt}^j according to the following Cobb-Douglas production function:

$$Y_{mt}^{j} = \theta_t (U_t^j K_t^j)^{\alpha} (L_{ut}^j)^{1-\alpha} \tag{18}$$

where θ_t is a TFP shock:[13] $\log(\theta_t) = \rho_\theta \log(\theta_{t-1}) + \sigma_\theta \epsilon_t^\theta, \ \epsilon_t^\theta \sim iid$ (19)

Since intermediate goods become symmetric, the aggregate production function for the final output Y_t can be expressed as:

$$Y_t \approx Y_{mt} = \left(A_t^{\vartheta-1}\theta_t\right)\left(U_t K_t\right)^{\alpha}\left(L_{ut}\right)^{1-\alpha} \text{[14]} \tag{20}$$

The term in the first parentheses is the TFP, the product of $A_t^{\upsilon-1}$ that reflects endogenous productivity and θ_t that indicates exogenous variation. Overall, endogenous productivity effects enter into production through the aggregate of adopted technologies, A_t while θ_t was assumed stationary to make the endogenous productivity mechanism as the driving force of long-term growth.

Also, an intermediate-goods firm *j* creates factor demands as it chooses K_t^j, U_t^j, and L_{ut}^j to minimize its production cost, given p_{mt}, Q_t, D_t, w_{ut}, and the desired markup, ζ. This paper endogenizes the firm's capital utilization decision by making the depreciation rate $\delta(U_t^j)$ a function of capital utilization rate, U_t^j (Greenwood et al., 1988; Anzoategui et al., 2019). Moreover, working capital restrictions for intermediate-goods producers, w_t^r exist to enhance the quantitative

13) Since A_t is assumed to have no exogenous shock due to the data availability issue, the variation of θ_t becomes the TFP shock.

14) See Appendix for further details.

performance and introduce the endogenous mechanism in a small open economy model (Queralto, 2019). Then, the firm' s cost minimization problem for K_t^j, U_t^j, and L_{ut}^j gives:

$$\varsigma\omega_t^r = \frac{(1-\alpha)MMC_t^j Y_{mt}^j}{L_{ut}^j},$$

$$\varsigma\delta'\left(U_t^j\right)Q_t K_t^j = \frac{\alpha MMC_t^j Y_{mt}^j}{U_t^j},\ \varsigma\left(D_t + \delta\left(U_t^j\right)Q_t\right) = \frac{\alpha MMC_t^j Y_{mt}^j}{K_t^j} \tag{21}$$

Here, the desired markup was assumed to be smaller than the optimal markup ϑ to avoid the threat of imitators' entry (Aghion and Howitt, 1997; Anzoategui et al., 2019).

3.1.4. Innovators and adopters

This section is where productivity becomes endogenous (Comin and Gertler, 2006; Anzoategui et al., 2019). The process of innovation is divided into two parts to reflect realistic lags in technology adoption: creating new technologies and adopting some of them. Thus, R&D expenditure increases the stock of technologies, Z_t, while adoption expenditure increases the stock of adopted technologies, A_t. Accordingly, there are innovators and adopters in the R&D sector and the adoption sector, respectively.

1) Innovators: Z_t as a result of R&D

A continuum, measure unity, of innovators creates new technologies with skilled labor. L_{srt}^p indicates skilled labor employed by an innovator p in R&D, and L_{srt} the aggregate of L_{srt}^p, which an individual innovator takes as given. Then a unit of skilled labor at t create Φ_t, the number of new technologies at $t+1$:

$$\Phi_t = \chi_t Z_t L_{srt}^{\rho_z - 1} \tag{22}$$

where χ_t ***is a random shock:***

$$\log(\chi_t) = (1-\rho_\chi)\chi + \rho_\chi \log(\chi_{t-1}) + \sigma_\chi \epsilon_t^\chi,\ \epsilon_t^\mu \sim iid \tag{23}$$

Based on Romer (1990), Z_t reflects public knowledge in the R&D process which the innovator also accepts as given. Besides, it is assumed $\rho_z < 1$ since constant returns to scale in R&D at the individual innovator level simplifies the aggregation of individual R&D. However, the marginal increase in the efficiency of R&D diminishes as the aggregate R&D increases at the aggregate level. Thus, innovator p' s decision problem can be expressed as:

$$\max_{L_{srt}^p} E_t\left\{\Lambda_{t,\ t+1} J_{t+1} \Phi_t L_{srt}^p\right\} - w_{st} L_{srt}^p$$

where J_t is the value of an unadopted technology. This gives

$$E_t\left\{\Lambda_{t,\ t+1} J_{t+1} \chi_t Z_t L_{srt}^{\rho_z - 1}\right\} = w_{st}. \tag{24}$$

The left-hand side is the marginal benefit, and the right-hand side is the marginal cost. Note that J_t and L_{srt} exhibit procyclical movements since profits from intermediate goods are procyclical, and J_t depends on expected future profits.

For a realistic approach, this model further includes technological obsolescence. The evolution of technologies is represented as: $Z_{t+1} = \Phi_t L_{srt} + \phi Z_t$, where ϕ is the survival rate for the technology of time *t,* and the first term $\Phi_t L_{srt}$ reflects the creation of new technologies by the aggregate number of skilled labor working in the R&D sector. This evolution can also be expressed as $Z_{t+1}/Z_t = \chi_t L_{srt}^{\rho_z} + \phi$ to verify that ρ_z is the elasticity of the growth rate of R&D technologies to the skilled labor in R&D.

2) Adopters: A_t as a result of Technology Adoption

The stock of technologies Z_t cannot affect productivity yet since this stock of technologies has to be converted into A_t through adoption. An adopter converts unadopted technologies into usable ones. A competitive aggregate of adopters was

assumed to facilitate summation. They buy the unadopted technology from the innovators at the competitive price, J_t. Subsequently, they use skilled labor to convert this technology into a usable one.

Here, such adoption process, or technology diffusion, was assumed to take time on average (Comin and Hobijn, 2010), and the adoption rate to change endogenously (Comin, 2009; Anzoategui et al. 2019). The speed of adoption depends on Z_t and L_{sat} that are used in adoption. The probability of success in making the technology usable in any given period is $\lambda_t = \lambda(Z_t L_{sat})$ with $\lambda' > 0$, $\lambda'' < 0$. It implies that the adoption process becomes more efficient by a spillover effect as the economy's general technological level enhances. This spillover is conducive to constructing the model since it guarantees a balanced growth path. Moreover, the reciprocal of this probability can represent the average adoption process time. If this probability is not on the steady-state value $\bar{\lambda}$, the speed of adoption will change as L_{sat} does. Lastly, unlike the R&D effort, no exogenous shock was assumed to the output of adoption activities, productivity, due to the lack of relevant data.

Once the technology becomes usable through adoption, the right to it is sold to an intermediate-goods producer. If Π_{mt} indicates the profits of this firm that result from its monopolistically competitive pricing on the good it produces, then the value of the adopted technology,

$$V_t = \Pi_{mt} + \phi E_t\{\Lambda_{t,\ t+1} V_{t+1}\}. \tag{25}$$

The right-hand side is the present value of profits from producing intermediate-goods. Hence, the adopter's maximization problem becomes:

$$J_t = \max_{L_{sat}} E_t\{-w_{st} L_{sat} + \phi \Lambda_{t,\ t+1}[\lambda_t V_{t+1} + (1-\lambda_t) J_{t+1}]\} \tag{26}$$

This recursive equation consists of total adoption cost and the total discounted benefit. The first-order condition is:

$$\lambda' \phi E_t\{\Lambda_{t,\ t+1}[V_{t+1} - J_{t+1}]\} = w_{st} \tag{27}$$

The left-hand side is the marginal benefit from additional adoption while the

right-hand side represents the marginal cost. Note that $V_t - J_t$ is procyclical as the value of adopted technologies is more strongly affected by short term profits than unadopted ones. Therefore, L_{sat} and accordingly, the pace of adoption changes procyclically.

Since λ_t is independent of individual-specific characteristics, the summation across adopters provides the evolution of adopted technologies:

$$A_{t+1} = \lambda_t \phi [Z_t - A_t] + \phi A_t \tag{28}$$

where $Z_t - A_t$ is the stock of unadopted technologies.

3.1.5. Equilibrium conditions

The resource constraint can be obtained by putting the equilibrium conditions into the household budget constraint.

$$Y_t = C_t + Q_t I_t + R_{t-1} B_{t-1} - B_t - w_{st} L_{st} + w_t^r L_{ut} \tag{29}$$

The market-clearing condition for skilled labor is

$$L_{st} = (Z_t - A_t) L_{sat} + L_{srt} \tag{30}$$

Trade balance depends on total domestic debt:

$$TB_t = R_{t-1} B_{t-1} - B_t \tag{31}$$

Finally, the model with the endogenous productivity channel features long-run growth in aggregate TFP and output (Anzoategui et al., 2019; Queralto, 2019).

3.2. The model with exogenous productivity

The analysis of the standard small open economy model is necessary to compare the result with that of the model above. All parts of the model are the same as above except the parts related to A_t. The growth rate of A_t was assumed to follow an exogenous process as in the literature (Aguiar and Gopinath, 2007):

$$g_t = A_{t+1}/A_t, \ \log(g_t/\mu_g) = \rho_g \log(g_{t-1}/\mu_g) + \sigma_g \epsilon_t^g \ \textbf{\textit{where}} \ \epsilon_t^g \sim \textbf{\textit{iid}} \tag{32}$$

Table 1. Calibrated Parameters

Parameter	Description	Value
R	Gross foreign interest rate	1.0025
δ	Capital depreciation rate	1.03^4-1
ω	Elasticity of marginal depreciation to utilization	0.006
α	Share of capital	0.3132
σ	Intertemporal elasticity of substitution	2
w_1	Frisch labor supply elasticity	1.6
ρ_λ	Adoption elasticity	0.925
ζ	Steady-state intermediate-goods markup	1.18
$\overline{d}$	Foreign Debt-to-trend ratio	0.007
λ	Adoption lag	0.2/4
θ_w	Working capital requirement	1

Ⅳ. Model Analysis

The macroeconomic models were solved in two stages: they were detrended to obtain stationary systems; and they were log-linearly approximated around the steady-state of those stationary systems.

4.1. Parameters

4.1.1. Calibrated parameters

The calibrated parameters are summarized in Table 1. Gross foreign interest rate is from Chang and Fernández (2013), the depreciation rate of capital, Frisch labor supply elasticity, and foreign debt-to-trend ratio from Garcia-Cicco et al. (2010), the elasticity of marginal depreciation to utilization and working capital requirements from Queralto (2019), the share of capital in the production function and intertemporal elasticity of substitution from both Garcia-Cicco et al. (2010) and Chang and Fernández (2013), adoption elasticity, steady-state intermediate-goods markup, and adoption lag from Anzoategui et al. (2019).

Note that $\upsilon = 2-\alpha$ to make this model follow a balanced growth path (Kung and Schmid, 2015; Queralto, 2019). This parametrization makes the endogenous productivity into pure labor productivity. However, some parameters on the

adoption process were borrowed from Anzoategui et al. (2019) due to the lack of relevant data.

4.2. Result Analyses - Why endogenous productivity?

This paper has three initiatives: to explain the persistent and severe downturns after financial crises; to examine exogenous technology shocks which have been stressed in the literature; and to assign a proper mechanism for the relationship between an interest rate and productivity in the literature. In order to find answers, this paper examines productivity with the assumption that it is endogenous.

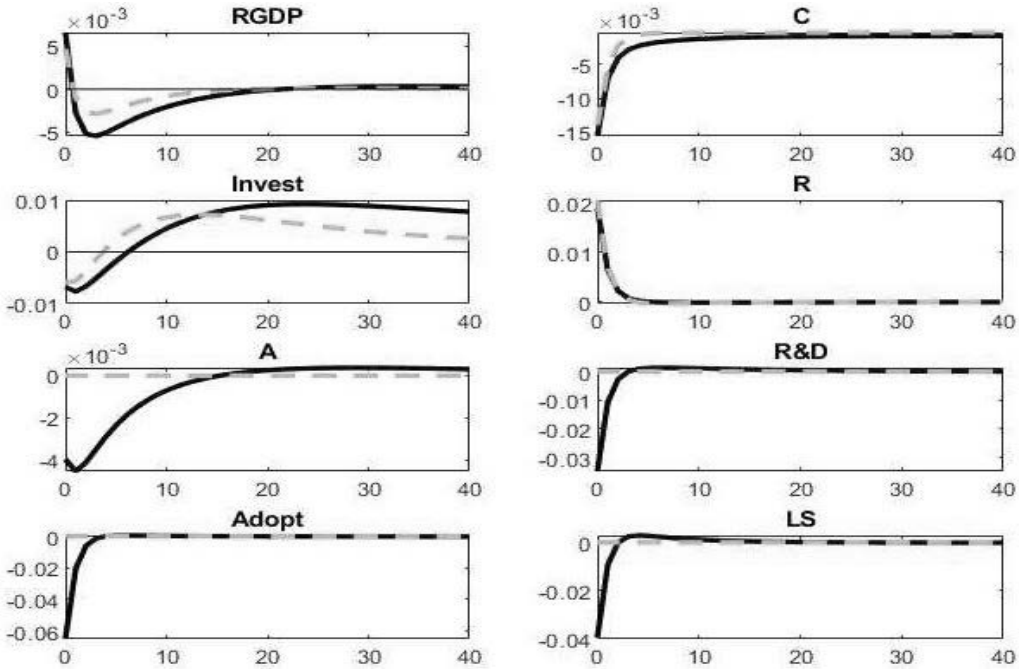
4.2.1. Persistent and severe downturns

1) Counter-factual analysis

Most importantly, it should be verified whether endogenous productivity is conducive to explaining more persistent and severe downturns following financial crises. Thus, a counter-factual analysis follows. In the counterpart model, productivity was assumed exogenous as in section 3.2. Figure 3 shows the economy' s dynamics to an exogenous shock: a rise in the country risk premium. Specifically, this paper focuses on a risk premium shock because it is a crucial variable in the business cycles of emerging markets (Neumeyer and Perri, 2005; Fernandez-Villaverde et al., 2011; and Chang and Fernandez, 2013).

Also, note that they were used to represent financial shocks, especially in financial crises (Anzoategui et al., 2019; Queralto, 2019). The figure summarizes several macroeconomic variables' impulse responses to the one standard error risk premium shocks. The names of responding variables are denoted at the top. The graph named R depicts the response of the epicenter variable. The rest of the figure describes the responses of output, consumption, and investment as well as three key productivity-related variables - the aggregate productivity, the R&D expenditure, and the adoption expenditure. Note that all the responses represent the percent changes from the steady-state value in quarterly frequencies. The

Figure 3. Impulse responses of macroeconomic variables to the risk premium shock



straight lines are the impulse responses of the model with the endogenous productivity while the dotted lines are those of the standard model with the exogenous productivity.

From the response of R, the shocks can be identified. To the one standard error risk premium shocks, real interest rates in both models rise to approximately 0.02% and return to the initial level in five quarters. Note that this similarity is necessary because the difference should be qualitative, not quantitative. In other words, if the shocks were bigger in the model with endogenous productivity, it would not be reasonable to compare the responses because the difference could come from the different sizes of the shocks. In response to these shocks, consumption and capital investment decrease more severely and persistently in the endogenous productivity model. The consumption in the endogenous productivity model decreases by approximately 0.02% while that of the exogenous productivity model diminishes by around 0.01%. The capital investments in both models drop by around 0.01%, but the drop is bigger in the former. Also, the returns of both

variables to the initial level are much slower in the model with endogenous productivity. In case of the capital investments, it is after seven and four quarters, respectively.

Furthermore, business R&D investment and adoption expenditure in the model with endogenous productivity plummeted by approximately 0.03% and 0.06%. They return to the initial level in five quarters. However, such a drop in R&D and adoption expenditure cannot be found in the other model because these factors were assumed exogenous literally. Accordingly, productivity in the model with exogenous productivity does not change much. This, in the end, results in more persistent and severe impacts on output. Real GDP in the endogenous productivity model decreases by approximately 0.005% while that in the exogenous productivity model diminishes by around 0.003%. Though real GDP returns to the original level eventually, it takes longer in the endogenous productivity model. It takes 21 quarters in the endogenous productivity model while it is 19 quarters in the other. As it is represented in eq (20) and (29), output decreases more severely and permanently in the endogenous productivity model.

In summation, these two models show qualitatively different reactions to the same shock. Specifically, the model with the endogenous productivity channel better captures the response of R&D, adoption, productivity, and output after financial crises. It verifies how R&D and adoption are damaged to the risk premium shocks and how this damage leads to the persistent and severe decline in output. Moreover, the results are consistent with the literature (Anzoategui et al., 2019; Queralto, 2019).

2) Why so different?

Indeed, the endogenous productivity model and the exogenous productivity model have different results. Thus, it is necessary to examine how the endogenous productivity model leads to such differences. To summarize, the main source of the differences is productivity.

The initiating disturbance to the country risk premium, all else equal, induces the exogenous risk premium to rise according to eq (11). As a result, the real interest rate increases following eq (10). Then, in response to the increase in the

real interest rate, households reduce their demand for consumption and risky saving. This is well represented in eq (8). The rise of the interest rate leads to the decline of the stochastic discount factor, which decreases consumption demand and increases the required return to capital. As a result, it leads to a drop in demand for capital investment and productivity-enhancing efforts by harshly discounting future profits. This can be verified in eq (24) and (26). Also, the demand for unskilled labor wanes as the working capital restrictions increase the cost of the labor input.

The result, the decline in output can be understood in two ways. According to the resource constraint, eq (29), the fall in capital investment and consumption demand reduces the output. However, the production function of intermediate goods firms, eq (20), shows that the drop in capital investment and unskilled labor demand decreases the output. Here the drop in unskilled labor demand comes from working capital restrictions.

Furthermore, the drop in productivity-enhancing investments harms productivity, amplifying the decline of output to be more persistent and severe than the model with exogenous technology. As a result, aggregate demand and output drop in the short term. However, in the medium and long term, the growth rates and levels of TFP and real GDP decline to larger scales. To summarize, the endogenous productivity channel plays a significant role in amplifying the country' s premium shock effect.

4.2.2. Productivity and an interest rate

This model provides a proper mechanism that was ad hoc in the literature by endogenously considering R&D, adoption, and productivity. Oviedo (2005), Aguiar and Gopinath (2008), and Chang and Fernández (2013) argue that a link between productivity and the interest rate is necessary to build models replicating emerging market business cycles. However, this relationship is evident since macroeconomic variables affect R&D, adoption, and, accordingly, productivity. Most importantly, this result explains what exogenous technological shocks can be because the change of a macroeconomic variable affects productivity-enhancing investment and productivity.

Ⅴ. Conclusion

This paper identifies qualitative differences in the behaviors of R&D, adoption, and productivity between financial crises and the other recessions. Then it constructs a quantitative macroeconomic model to connect the qualitative differences to persistent and severe downturns after financial crises. The main findings indicate that the decline of R&D, adoption, and productivity can explain the persistent and deep recessions after financial crises. This result is consistent with the literature (Anzoategui, D. et al., 2019; Queralto, 2019). In contrast, the result suggests that the exogenous productivity mechanism has a limited role in explaining the downturns of productivity and output after financial crises.

Also, this endogenous productivity mechanism explains how exogenous technological shocks could result in a change in productivity. Thus, it assigns a proper relationship between productivity and an interest rate that was ad hoc in the literature (Oviedo, 2005; Aguiar and Gopinath, 2008; Chang and Fernández, 2013).

However, there is still room for improvement. First, it would be a great advancement to finish the estimation of the macroeconomic model and develop the paper based on the result. Second, it is also desirable to collect the data on adoption and analyze it as in Anzoategui, D. et al. (2019). It requires a survey data of emerging market firms which is currently not available. Third, it would be a noteworthy extension to include government fiscal policy and analyze welfare gains. Monetary policies in several emerging markets are relatively new and have limits, and fiscal policies can target specific targets. Thus, introducing fiscal policies into this framework would be more appropriate. Exploring how this fiscal policy can be useful in the business cycle with the endogenous productivity mechanism would be worthwhile. Gertler and Kiyotaki (2010), Gertler et al. (2012), and Akinici and Queralto (2016) examine how government intervention could mitigate the powerful impact of the financial crises. Analyzing this topic with the endogenous TFP mechanism might provide another policy implication.

In summation, the results stress the effects of demand factors on the supply side. This is important since it can explain the persistent downturns after financial crises and provide an insight into exogenous technological shocks.

References

Aguiar, M. and G. Gopinath (2006). "Emerging market fluctuations: The role of interest rates and productivity shocks." Current Account and External Financing.

Aguiar, M. and G. Gopinath (2007). "Emerging market business cycles: The cycle is the trend." Journal of Political Economy 115(1): 69-102.

Anzoategui, D., et al. (2019). "Endogenous technology adoption and R&D as sources of business cycle persistence." American Economic Journal: Macroeconomics 11(3): 67-110.

Aw, B. Y., et al. (2011). "R&D investment, exporting, and productivity dynamics." American Economic Review 101(4): 1312-1344.

Basu, S. and M. S. Kimball (1997). "Cyclical productivity with unobserved input variation." National Bureau of Economic Research.

Benigno, G. and L. Fornaro (2017). "Stagnation traps." The Review of Economic Studies 85(3): 1425-1470.

Boileau, M. and M. Normandin (2017). "The price of imported capital and consumption fluctuations in emerging economies." Journal of International Economics 108: 67-81.

Boz, E., et al. (2011). "Emerging market business cycles: Learning about the trend." Journal of Monetary Economics 58(6-8): 616-631.

Brauer, M., et al. (2016). "The Next Generation of the Penn World Table." World Bank Seattle.

Cerra, V. and S. C. Saxena (2008). "Growth dynamics: the myth of economic recovery." American Economic Review 98(1): 439-457.

Chang, R. (2015). “Commodity Price Fluctuations and Monetary Policy in Small Open Economies.” Commodity Prices and Macroeconomic Policy 22: 019-050.

Chang, R. and A. Fernández (2013). “On the sources of aggregate fluctuations in emerging economies.” International Economic Review 54(4): 1265-1293.

Christiano, L. J., et al. (1999). “Monetary policy shocks: What have we learned and to what end?” Handbook of macroeconomics 1: 65-148.

Comin, D. and M. Gertler (2006). “Medium-term business cycles.” American Economic Review 96(3): 523-551.

Crépon, B., et al. (1998). “Research, Innovation And Productivity: An Econometric Analysis At The Firm Level.” Economics of Innovation and new Technology 7(2): 115-158.

Fernández, A. and A. Gulan (2015). “Interest rates, leverage, and business cycles in emerging economies: The role of financial frictions.” American Economic Journal: Macroeconomics 7(3): 153-188.

Fernández-Villaverde, J., et al. (2011). “Risk Matters: The Real Effects of Volatility Shocks.” American Economic Review 101(6): 2530-2561.

Garcia-Cicco, J., et al. (2010). “Real business cycles in emerging countries?” American Economic Review 100(5): 2510-2531.

Greenwood, J., et al. (1988). “Investment, capacity utilization, and the real business cycle.” The American Economic Review: 402-417.

Guellec, D. and B. v. P. De La Potterie (2002). “R&D and productivity growth.” OECD Economic studies 2001(2): 103-126.

Hanson, G. H. (2010). “Why isn’t Mexico rich?” Journal of Economic Literature 48(4): 987-1004.

Herbst, E. P. and F. Schorfheide (2015). "Bayesian estimation of DSGE models." Princeton University Press.

Jaimovich, N. and S. Rebelo (2009). "Can news about the future drive the business cycle?" American Economic Review 99(4): 1097-1118.

Justiniano, A., et al. (2011). "Investment shocks and the relative price of investment." Review of Economic Dynamics 14(1): 102-121.

Kortum, S. and J. Lerner (2001). "Does venture capital spur innovation? Innovatorial inputs and outcomes: New studies of innovatorship in the United States." Emerald Group Publishing Limited: 1-44.

Kortum, S. S. and J. Lerner (2000). "Assessing the impact of venture capital on innovation." RAND Journal of Economics, Winter.

Laeven, L. and F. Valencia (2013). "Systemic banking crises database." IMF Economic Review 61(2): 225-270.

Mendoza, E. G. (1991). "Real business cycles in a small open economy." The American Economic Review: 797-818.

Neumeyer, P. A. and F. Perri (2005). "Business cycles in emerging economies: the role of interest rates." Journal of Monetary Economics 52(2): 345-380.

Oviedo, P. M. (2005). "World interest rate, business cycles, and financial intermediation in small open economies." Staff General Research Papers Archive 12360, Iowa State University, Department of Economics.

Queralto, A. (2019). "A model of slow recoveries from financial crises." Journal of Monetary Economics.

Reinhart, C. M. and V. R. Reinhart (2010). "After the fall." National Bureau of Economic Research.

Reinhart, C. M. and K. S. Rogoff (2009). "This time is different: Eight centuries of financial folly." Princeton university press.

Romer, P. M. (1990). "Endogenous technological change." Journal of Political Economy 98(5, Part 2): S71-S102.

Romer and Romer (1989). "Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz." National Bureau of Economic Research.

Schmitt-Grohé, S. and M. Uribe (2003). "Closing small open economy models." Journal of International Economics 61(1): 163-185.

University of Groningen and University of California, Davis, "Total Factor Productivity at Constant National Prices for Mexico."

Uribe, M. and V. Z. Yue (2006). "Country spreads and emerging countries: Who drives whom?" Journal of International Economics 69(1): 6-36.

Appendix

Qualitative measures

This paper borrows the qualitative measures of financial crises from Laeven and Valencia (2013). They define a banking crisis with (1) significant signs of financial distress in the banking system and (2) significant banking policy intervention measures in response to significant losses in the banking system. They also define a currency crisis as an at least 30 percent nominal depreciation of the local currency relative to the U.S. dollar that is also at least ten percentage points higher than the rate of depreciation in the year before. Then this paper aggregates these two crises and defines it as financial crises.

On the other hand, the measures for the other recession were constructed as in OECD-based Recession Indicators. Real GDP was log-detrended. Then this paper selects the other recession periods based on this log-detrended data not to overlap with the documented financial crises.

Model specification

- The adjustment cost function, $s(\cdot)$, is increasing and concave with $s(\cdot) = s'(\cdot) = 0$ and $s''(\cdot) > 0$ as in the literature.
- The success probability of adoption: $\lambda(\bullet) = \kappa_\lambda(\bullet)^{\rho_\lambda}$, an increasing and concave function. κ_λ and $0 < \rho_\lambda < 1$ are constants.
- The depreciation rate: $\delta(U_t) = \delta - d_1/(1+\omega) + d_1 U_t^{1+\omega}/(1+\omega)$, an increasing and convex function.
- The working capital restrictions: $\omega_t^r = \left(1 + \frac{\theta_w(R_t - 1)}{R_t}\right) w_{ut}$
- The production function: $Y_t \simeq \overline{Y_t}$ since $\int_0^{A_t} K_t^j dj = K_t$ and $\int_0^{A_t} L_t^j dj = L_t$

국문초록

이 논문은 개발도상국에서 금융 위기의 여파가 장기간 지속되는 현상을 분석하기 위해 Research & Development (R&D), 기술 채택, 그리고 생산성의 역할을 탐구한다. 우선 통계적 분석은 금융 위기가 다른 위기에 비해 R&D, 생산성, 그리고 생산물을 더 크고 지속적으로 감소시킴을 보여준다. 이와 같은 생산성 관련 변수들의 움직임과 생산물의 움직임은 데이터에 기반한 거시 경제 모형을 통해 연결되었다. 모형은 국제 실물 경기변동 이론 (International Real Business Cycle model; IRBC model) 위에서 내생적인 생산성을 가지도록 설계되었다. 구체적으로 R&D와 기술채택은 개발도상국의 경기 순환에서 중요하다고 판단되는 외생적 충격들에 영향을 받는다고 가정되었다. 위험 프리미엄의 증가는 여러 종류의 수요들을 줄이기 때문에, R&D와 기술채택 분야가 비활성화되고 생산성과 생산물의 성장은 그렇지 않을 경우보다 더욱 심하게 감소하게 된다. 주요 결과에 따르면 금융 위기는 수요 변수들에 영향을 미치는데, 이 여파가 내생적인 생산성 메커니즘을 통해 경제에 더 지속적이고 강력한 영향을 가지게 된다. 또한 일반적인 관점에서 이 모형은 거시 경제 변수의 변화에 따른 생산성 변화에 대한 통찰력을 제공한다. 이는 개발도상국의 경기순환에서 중요한 요소임에도 불구하고 잘 연구되지 않았던 부분이다. 그럼으로써 이 모형은 선행연구에서 임의로 주어졌던 이자율과 생산성 사이의 관계에 대한 이론적 근거를 부여한다.

주요어 : 금융위기, R&D, 기술채택, 경기순환
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