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The Effect of Financial Innovation on Economic Growth: A Theoretical Model

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ABSTRACT

In contrast to the abundant theoretical literature on the finance-growth nexus, there is a lack of research that directly examines the impact of financial innovation on growth models. This study proposes a theoretical model that systematically interprets the transmission mechanism of how financial innovation affects economic growth. By establishing a paradigmatic economy, the research constructs a model based on the microeconomic foundations of four main agents: households, financial innovators, financial intermediaries, and firms. The influence of financial innovation on economic growth is examined through the actions of each agent. The results of the model demonstrate a positive external effect of existing financial innovations leading to the creation of new financial innovations. Additionally, new financial innovations enhance the efficiency of financial intermediaries. Moreover, an increase in financial intermediary efficiency leads to higher savings and investment. Consequently, new financial innovations contribute to the enrichment of the capital stock and have a positive impact on economic growth. This research provides a theoretical basis for conducting empirical studies and implementing policies.

Keywords: financial innovation; financial innovators; financial intermediaries; microeconomic foundation; capital stock; economic growth; Solow growth theory; theoretical model

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INTRODUCTION

A diverse body of research has developed and modified theoretical models to enrich our understanding of the finance-growth nexus. Extensive research has demonstrated several mechanisms by which the introduction of financial intermediaries, financial instruments and financial markets could boost economic growth through enhancing resource allocation for investments [1–3], reducing transaction cost [4, 5], enabling trading and hedging activities to deal with risk [6–9], and facilitating technological innovation [10–13]. Meanwhile, little attention has been devoted to directly capturing the role of financial innovation in the model of growth.

Extant theoretical works have demonstrated the effect of financial innovation on economic growth but they also exhibited limitations. Chou [14] modelled the linkage between financial innovation and economic growth based on the growth theory of Solow [15]. Through connecting the efficiency of financial intermediaries with producing financial innovation, Chou [14] explored directly the positive link of financial innovation and economic growth. However, Chou [14] neglected to consider microeconomic foundation in terms of how each agent makes decisions. Thus, there is no clear transmission channel how financial innovation affects economic growth.

Approaching the other side, Laeven et al. [16] considered the role of financial innovation in improving the screening of borrowers' performance and its effect on endogenous growth. Laeven et al. [16] addressed the core implication that technological innovation and financial innovation have a positive relation. Also, the growth of an economy would eventually stagnate if financiers do not innovate. The deficiency of this study is that financial innovation was limited in capturing any changes in the financial system that could improve the screening efficiency in identifying capable innovation projects by entrepreneurs. Similarly, the financier agent is constructed to play a simple role in screening the idea of entrepreneurs. Moreover, this study neglected the essential role of financial institutions in mobilizing savings in the households, allocating capital in the economy and facilitating the development of the financial markets.

In this research, we construct the model based on the microeconomic foundation in a paradigm economy to examine the implications of introducing financial innovations in the framework of the Solow growth model. By doing that, we could interpret systematically how introducing new financial innovations in the economy affects mobilizing more capital from savings of households through financial intermediaries in the economy. This study captures financial innovations in a broad spectrum from its production and application in the financial system. Based on the conceptual framework, financial innovations in this model are determined as a new class of financial products or services that functions the activities of financial intermediaries. The production of new financial innovations has the positive spillover effect which means that the invention of new one also is supported by innovating and modifying existing financial products and services. We have constructed the paradigm of the economy that includes four types of agents: households, financial innovators, financial intermediaries and firms.

The remainder of this paper is organized as follows. In the next section, we will describe the environment and the framework of the model based on microeconomic foundation. Also, in this section we will explore the objective functions of each agent, and solve for the solutions in the steady-state equilibrium. Consequently, there is a clear transmission channel on how financial innovation affects economic growth. This is followed by a results and discussion section and a conclusion.

MODEL

Environment and Research Framework

The environment consists of four agents: households, financial innovators, financial intermediaries and firms. Their characteristics will be described in more detail later.

Households in this model consist of two-period-lived agents. During the young period (t), these agents are labor suppliers for both firms $\left(L_Y^S\right)$ and financial innovators $\left(L_\tau^S\right)$. They choose to allocate the number of labors in each sector. The wage rate of working for firms and financial innovators are w_Y and w_τ respectively. Hence, when they supply L_Y^S labor into firms, their labor income received

from firms is $w_Y L_Y^S$. Similarly, their labor income received from financial innovators is $w_\tau L_\tau^S$ if households contribute L_τ^S labors to financial innovators. The labor income of households is spent on consumption during this period (c_t) and the rest for saving (S_t) at the financial intermediaries. The amount of savings (S_t) would create saving income $(\gamma_S S_t)$ at the second period of their life. The old period $(t+1)$ is assumed that no labor income so household's consumption (c_{t+1}) is entirely funded from the saving (S_t) and interest of saving $(\gamma_S S_t)$. The objective of households is to maximize their utility function by allocating their consumption over two periods c_t and c_{t+1}.

The second agent is financial innovators who have a need to employ the workforce from the household in order to produce financial innovations. They decide to produce how many units of financial innovation in the financial system ($\dot{\tau}$). Their financial innovations are bought out by financial intermediaries with price $P_{\dot{\tau}}$. Hence, the revenue of financial innovators in this model is estimated by the value of $P_{\dot{\tau}}\dot{\tau}$. Households contribute L_τ^S labor to financial innovators with the wage rate being $w_{\dot{\tau}}$. Hence, the expenditure of financial innovators which is assumed only labor cost equals $w_\tau L_\tau^D$. By deciding on the demand for labor and the number of financial innovations produced, financial innovators will determine their optimal profit.

Next, financial intermediaries in this model are constructed in the traditional manner. They collect savings in the economy from households, and then allocate K capital to firms. Their income is determined by the interest of capital (γ_K) which they receive from firms' loan (K). The cost for financial intermediaries comes from interest payment for households' savings and purchasing financial innovations produced by financial innovators with $\dot{\tau}$ quantity of financial innovations and their price $P_{\dot{\tau}}$. The role of financial innovations in this model is facilitating the operation of financial intermediaries. Financial intermediaries would evaluate the price of financial innovations and the interest rate on savings in order to maximize their profit.

Lastly, firms are the final agent in the economy. They employ labor from households and capital from financial intermediaries as inputs to produce final goods and earn the value of Y as outputs. With the quantity of labor is represented as L_Y^D at wage w_Y, and the labor cost for firms equals $w_Y L_Y^D$. They borrow K units of capital from financial intermediaries with the interest rate of borrowed capital being γ_K, hence the capital cost of firms would be $\gamma_K K$. Their objective is to maximize profits by estimating the value of wage (w_Y) and the interest rate of borrowed capital (γ_K).

In terms of the timing of the model, households are the first to allocate labor to financial innovators and firms. Next, financial innovators are the second to produce new financial innovations which facilitate the activities of financial intermediaries. The third mover is financial intermediaries who use savings to lend external capital of firms. Firms are the last in this economy to produce final goods.

The connection between four players including households, financial innovators, financial intermediaries and firms is illustrated in *Figure*.

Based on the framework, we consider the decisions of each agent in the following way.

HOUSEHOLDS

The objective of households is to determine their consumption in two periods c_t and c_{t+1} in order to maximize their utility function together with their budget constraint. The price of consumption is set to be one (as a numeraire good). The households' utility maximization problem is a function of c_t and c_{t+1} as follows:

$$\max_{c_t, c_{t+1}} \ln c_t + \beta \ln c_{t+1}, \tag{1}$$

subject to:

$$w_Y L_Y^S + w_\tau L_\tau^S - c_t = S_t, \tag{2}$$

$$c_{t+1} = \gamma_S S_t + S_t, \tag{3}$$

$$L_Y^S + L_\tau^S = 1, \tag{4}$$

$$L_Y^S, L_\tau^S, c_t, c_{t+1} > 0. \tag{5}$$

Equation (2) implies the budget constraint in the young period of households where saving is estimated as the difference of their income and consumption. Equation (3) presents the budget constraint in the old-aged period. Their consumption is funded by savings and interest on savings accumulated from

the young period. Households are the only supplier of labor in the economy, including two sectors for working so we set it equal to 1 as equation (5).

As presented in *Appendix A*, the consumption of households in the first period (c_t) is derived:

$$c_t = \left(\frac{1}{1+\beta}\right) w \cdot \quad (6)$$

By deriving for the consumption of households, this model also obtains the results of wage: $w_\tau = w_Y = w$ (see *Appendix A*). This finding implies the wage of labor in financial innovation equals the wage of labor in firms. This creates a balance state in the labor market because if the wage of financial innovators is higher than that of firms, households would tend to work for financial innovators and do not choose to work for firms. Because the wage rate in both sectors does not have any different, households have free entry in these sectors. Therefore, the allocation of labor in this economy will be determined by the labor demand of financial innovators and firms.

The consumption of households in the second period c_{t+1} is derived:

$$c_{t+1} = (1+\gamma_S)\frac{\beta}{1+\beta} w \cdot \quad (7)$$

Financial Innovators

Financial innovators' objective is to maximize profits. Their profits are determined based on two decisions, encompassing the number of new financial innovations $(\dot{\tau})$ and the number of labors employed (L_τ^D). The profit maximization function could be written as follows:

$$\max_{\dot{\tau}, L_\tau^D} P_\tau \dot{\tau} - w_\tau L_\tau^D, \quad (8)$$

where $w_\tau L_\tau^D$ is the cost of labor engaged in producing financial innovation; P_τ denotes the unit price of financial innovations. In this research, the price of financial innovations is determined by financial intermediaries because financial innovations are only used for the operation of financial intermediaries. Then, financial innovators are price-takers.

Financial Innovation Production

This section focuses on constructing the production function of financial innovators. The operation

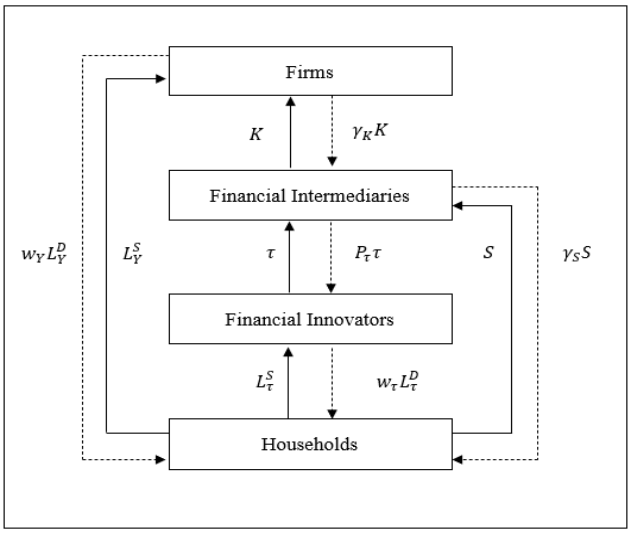

Fig. **Framework of the Theoretical Model**

Source: Compiled by the authors.

of financial innovators is to create new financial innovations. We assume that these innovations do not become obsolete (we exclude the effect of shocks such as the economic crisis, change in regulation, etc.). In particular, based on characteristics of existing financial innovations, financial innovators improve them to better versions and consider to be new financial innovations. This characteristic is presented by the term "positive spillover". Accordingly, the production process of creating new financial innovation is as follows:

$$\dot{\tau} = F\, L_\tau^{D\lambda}\, \tau^\phi, \quad (9)$$

where F is a parameter of productivity which captures the joint effects of factors such as new technology, managerial skill, labor skill and other factors which affect the change in production.

$\lambda \in (0,1)$ denotes the effect of labor on producing new financial innovations. In other words, λ presents how new financial innovations respond to the change of labor in the financial innovation sector. For example, when the value of $\lambda = 0.25$ implies the effect of labor on new financial innovations produced accounted for one quarter. Other factors account for three quarters.

τ^ϕ represents positive spillovers which could be explained by the fact that new financial innovations are created based on combining or innovating

characteristics of existing financial products or services.

$\phi \in (0,1)$ represents the effect of existing financial innovations on producing new financial innovations. Similarly to λ, we assume that $\phi \in (0,1)$ indicates the positive effect and diminishing marginal returns from existing financial innovations.

Solving for Financial Innovators

We obtain the workforce for producing financial innovations (see *Appendix B*):

$$L_{\tau}^{D} = \left(\frac{w}{\lambda P_{\tau} F \tau^{\phi}} \right)^{\frac{1}{\lambda - 1}}. \quad (10)$$

Also, we obtained the following results of $\dot{\tau}$:

$$\dot{\tau} = \left(F \tau^{\phi} \right)^{\frac{-1}{\lambda - 1}} \left(\frac{w}{\lambda P_{\dot{\tau}}} \right)^{\frac{\lambda}{\lambda - 1}}. \quad (11)$$

This result indicates that the number of new financial innovations $(\dot{\tau})$ depends positively on the productivity of creating new financial innovations (F), existing financial innovations (τ^{ϕ}), price of new financial innovations $(P_{\dot{\tau}})$ and depends negatively on the wage of labor (w). The effect of main factors including F, τ^{ϕ} and $P_{\dot{\tau}}$ on the number of new financial innovations produced $(\dot{\tau})$ is interpreted as follows.

Given the same input level, when financial innovators increase the productivity (F) in production, they can produce more new financial innovations $(\dot{\tau})$ because higher productivity leads to faster production at the same time. Consequently, financial innovators could increase their revenues and profits as well.

In terms of the positive effect of existing financial innovations (τ^{ϕ}), the intuition is that when we have higher numbers of existing financial innovations (τ^{ϕ}), financial innovators can produce more new financial innovations $(\dot{\tau})$. This is due to the existence of the positive spillovers effect. Financial innovators tend to use characteristics of existing financial innovation and then modify, combine or improve it into new financial innovations. Therefore, a variety of existing financial innovations is a good foundation for facilitating the innovation process in order to create better and more new financial innovations.

The higher financial innovations' price $(P_{\dot{\tau}})$ positively affects the number of financial innovations produced $(\dot{\tau})$. In the case that the price of financial innovations increases, the profit per unit of new financial innovations is also higher. As a result, financial innovators have more incentive to produce more new financial innovations.

Financial Intermediaries

Financial intermediaries play an essential role in the allocation of the capital resources in the economy from savings of households. The objective of financial intermediaries is to determine the interest of savings (γ_S) and the price of financial innovations $(P_{\dot{\tau}})$. The profit function of financial intermediaries can be summarized as follows:

$$\max_{\gamma_S, P_{\dot{\tau}}} \gamma_K K - \gamma_S S_t - P_{\dot{\tau}} \dot{\tau}. \quad (12)$$

Identifying the Role of Financial Innovation in the Financial System

Based on setting the link between saving, investment and capital in the Solow model, we determine the role of financial intermediaries in the economy. investment in the Solow model is always equal to saving. However, in our model, we have relaxed this assumption by introducing the parameter ξ to measure the effectiveness of intermediations in mobilizing savings into investment. Thus, the investment-savings linkage is specified:

$$I = \xi S. \quad (13)$$

We set the number of new financial innovations $(\dot{\tau})$ embodied for the measure of ξ

$$\xi \equiv \dot{\tau}. \quad (14)$$

That means in the link of savings and investment, the efficiency of financial intermediaries is presented by the new class of financial innovations. The introduction of a new type of financial innovation would reduce the cost of financial intermediation, improve the allocation of resources and provide a range of hedging possibilities. This could make

financial intermediaries more efficient [17–20]. For example, the author mentioned the introduction of credit cards in the 1950s. This product not only functions as a convenient payment method but also provides short-term loans. That facilitates users in lowering transaction cost and funding for their consumption. Also, operating new financial institutions such as mutual funds, micro finance and providing securities in the financial markets could reduce risk and offer a variety of investment choices for individual investors. These innovations make financial intermediaries more efficient and ultimately contribute to mobilizing the savings process. Hence, the number of new financial innovations $(\dot{\tau})$ plays an important role in the savings-investment process and is an important metric for ξ in our model.

Concerning the relationship between investment and capital, we used the Solow model to construct the change in capital stock. Denoting ΔK is the change of capital stock and I is the new investment added to capital stock. Now, let's take into account the depreciation of capital. We define depreciation as a value reduction of capital stock caused by obsolescence and wear out and denote δ as the depreciation rate of capital stock. The change in the capital stock over time is measured by investment minus capital depreciation:

$$\Delta K = I - \delta K. \tag{15}$$

At the steady state, the stock of capital will stay constant so $\Delta K = 0$, investment from equation (15) is derived as a function of capital:

$$I = \delta K. \tag{16}$$

From equation (13) and equation (16), the capital stock in our model now becomes:

$$K = \frac{\xi}{\delta} S. \tag{17}$$

We obtain the solution for the capital stock:

$$K = \frac{\beta}{1+\beta}\left(\frac{1}{\lambda}\right)^{\frac{\lambda}{\lambda-1}} \frac{\left(F\tau^{\phi}\right)^{\frac{1}{1-\lambda}} w^{\frac{2\lambda-1}{\lambda-1}}}{\delta} P_{\dot{\tau}}^{\frac{\lambda}{1-\lambda}}. \tag{18}$$

This result demonstrated that capital in the economy (K) depends positively on productivity in producing financial innovations (F), positive spillovers of existing financial innovations (τ^{ϕ}), the price of financial innovations $(P_{\dot{\tau}})$, and wage of labor (w).

Taking into account both productivity (F) and positive spillovers of existing financial innovations (τ^{ϕ}), these factors increase would lead to a raising of capital in the economy. As mentioned in the environment of financial innovator, F and τ^{ϕ} function as the important element in producing new financial innovations. With higher levels of productivity and existing financial innovations, there are more new financial innovations being created. Hence, its effect on capital could be interpreted through the engaging of financial innovations in the mobilized saving process and variety investment portfolio that would increase the level of capital stock in this economy. In particular, more new financial innovations are being introduced, and financial transactions being conducted more conveniently at lower cost. That mobilizes more savings into the financial intermediaries and increases the liquidity of capital. In addition, new financial innovations in financial institutions and financial markets provide more investment opportunities which can create more capital from savings. Overall, new financial innovations enhance the efficiency of financial intermediaries and consequently increase capital.

Also, higher price of financial innovation $(P_{\dot{\tau}})$ results in higher capital is explained by the profit-maximizing objective of financial intermediaries. The price of financial innovations increases the cost of purchasing financial innovations. That lowers the profit of financial intermediaries. In order to offset the highest costs, financial intermediaries must increase their revenue by allocating more capital which is the main source to generate their income. As a result, capital in the economy will reach a higher level.

Solving for Financial Intermediaries

The solution to the problem of the price of financial innovations is as follows (see *Appendix C*):

$$P_{\dot{\tau}} = \left[\frac{\beta}{1+\beta}\frac{\lambda}{\delta}\right]\gamma_K w.$$

By conducting the comparative statics, this result supports that the rental rate of capital (γ_K) and wage (w) exert positive effects on the price of new financial innovations while the depreciation rate of capital stock (δ) negatively affects on the price of new financial innovations $(P_{\dot{\tau}})$.

As mentioned in the *Appendix A*, S_t does not depend on γ_S so financial intermediaries will set γ_S as low as possible. In order to maximize their profits, financial intermediaries should minimize the costs paid for households' savings interest. Hence, γ_S is determined equal to 0 in this model.

Firms

The objective of firms is to maximize their profits in the final goods industry. Y is the output of firms that also is firms' revenue. This model applies the traditional Solow growth model with a Cobb-Douglas form of output. Capital provided by financial intermediaries (K) and workforce in the final good sector (L_Y^D) are two input factors so the output function can be written as:

$$Y = AK^{\alpha}\left(L_Y^D\right)^{1-\alpha}.$$

This model assumes that firms have two expenditures including labor cost $(w_Y L_Y^D)$ and cost for using external capital with γ_K is the interest rate of borrowed capital (K). The objective of firm is to determine how much is the optimal wage (w_Y) and the interest rate for loans borrowed from financial intermediations (γ_K) in order to maximize their profit as follows:

$$\max_{w_Y,\gamma_K} Y - w_Y L_Y^D - \gamma_K K.$$

By taking the first derivative with respect to w and γ_K, we can show that there are solutions for firms in identifying the optimal wage (w) and the interest rate on loans (γ_K) to maximize their profit (see *Appendix D*).

RESULTS AND DISCUSSION

1. There is a positive spillover effect from existing financial innovations to new financial innovations.

Our result demonstrate that with a higher level of existing financial innovation (τ^{ϕ}), financial innovators are more likely to create new financial products and services $(\dot{\tau})$. This is due to the fact that production of new financial innovations is also based on existing financial innovations to create the new one through combining, modifying, and innovating them.

2. New financial innovations have a positive effect on the efficiency of financial intermediaries

An increase in new financial innovations produced $(\dot{\tau})$ could enhance the efficiency of financial intermediaries (ξ). This is because using new financial innovations can reduce transaction costs and mitigate risk. That makes financial transactions more convenient and financial intermediaries work more efficiently.

3. The efficiency of financial intermediaries has a positive effect on saving and investment

Through the effect of financial innovation, financial intermediaries work more efficiently and result in higher saving and investment (see *Equation 13*). This is due to the financial intermediaries is facilitated infrastructure and instruments that enhance the liquidity of capital flows in the economy and increase the mobilizing savings into the investment process. Additionally, operating more efficiently of financial intermediaries can satisfy the needs of individual savers and investors.

4. New financial innovations have a positive effect on capital and economic growth.

An increase in financial innovations $(\dot{\tau})$ results in higher capital stock (K), greater output (Y) and economic growth. The transmission channel on how financial innovations affect economic growth is interpreted as follows. The advent of new financial products and processes in the banking system could enhance the convenience of financial transactions and lower cost of transactions. This results in more liquidity of capital and more mobilized savings. Hence, financial innovation enriches the source of capital, the capital stock thus increases. In the context of firms, they could conveniently capture a variety of capital sources from the financial system. Thus, the interactions of financial innovation, financial intermediaries and firms address the increasing of capital in the economy. In this way, a variety of capital sources facilitate expanding firms' business activities, producing more finished goods and accelerating economic growth.

CONCLUSION

The model demonstrates a positive spillover effect of existing financial innovations on

development of new financial products. This presents the continuation of producing new financial innovations. Additionally, the positive effect of new financial innovation on the efficiency of financial intermediaries presented by a higher number of new financial innovations results in the operation of financial intermediaries more efficiently. Moreover, with higher efficiency, financial intermediaries play a positive role in saving and investment. Finally, we pointed out the positive effect of new financial innovations on economic growth. These activities efficiently mobilize savings and enhance capital resources for businesses, accelerating economic growth.

Our findings provide an overall understanding of the transmission channel on how financial innovation is linked to economic growth. Based on this, the policymakers should take into account the benefits of financial innovation when formulating policies. Also, our evidence provides a theoretical foundation for developing further empirical research in specific cases.

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APPENDIXS

APPENDIX A

Derivation of the Consumption for Households

From equation (2), deriving for $c_t = w_Y L_Y^S + w_\tau L_\tau^S - S_t$.

From equation (4), substituting $L_Y^S = 1 - L_\tau^S$ into equation of c_t:

$$c_t = w_Y \left(1 - L_\tau^S\right) + w_\tau L_\tau^S - S_t.$$

By substituting c_t and c_{t+1} into equation (1), we obtain households' utility maximization problem:

$$\max_{L_\tau^S, S_t} \ln\left[w_Y \left(1 - L_\tau^S\right) + w_\tau L_\tau^S - S_t\right] + \beta \ln\left[S_t \left(1 + \gamma_S\right)\right].$$

By taking the first derivative with respect to L_τ^S and S_t, we obtain $w_\tau = w_Y = w$.

Deriving the result of S_t, c_t, c_{t+1} as follows:

$$S_t = \frac{\beta}{1+\beta} w.$$

From the second component of households' utility maximization problem, we deduce that $\beta \ln\left[S_t \left(1+\gamma_S\right)\right] = \beta \ln S_t + \beta \ln\left(1+\gamma_S\right)$. Hence, when taking the first derivative of the maximization function with respect to S_t, γ_S was gone. Besides, the result of S_t indicated that S_t only depends on, so households tend to send their savings into financial intermediaries and do not care about the interest rate in the economy.

Deriving the result of c_t, c_{t+1} as follows:

$$c_t = \left(\frac{1}{1+\beta}\right) w,$$

$$c_{t+1} = (1+\gamma_S) \frac{\beta}{1+\beta} w.$$

APPENDIX B

Derivation of Financial Innovation and the Labor Demand for Financial Innovators

From equation (9), we substitute $\dot{\tau}$ into equation (8) and obtain:

$$\max_{L_\tau^D} P_\tau F L_\tau^{D\lambda} \tau^\phi - w_\tau L_\tau^D.$$

The first order conditions with respect to L_τ^D indicates the labor demand function:

$$L_\tau^D = \left(\frac{w_\tau}{\lambda P_\tau F \tau^\phi}\right)^{\frac{1}{\lambda - 1}}.$$

Given $w_\tau = w$, we also rewrite L_τ^D as:

$$L_\tau^D = \left(\frac{w}{\lambda P_{\dot{\tau}} F \tau^{\phi}} \right)^{\frac{1}{\lambda - 1}},$$

by substituting L_τ^D into equation (9), we obtain the function for $\dot{\tau}$:

$$\dot{\tau} = \left(F \tau^{\phi} \right)^{\frac{-1}{\lambda - 1}} \left(\frac{w}{\lambda P_{\dot{\tau}}} \right)^{\frac{\lambda}{\lambda - 1}}.$$

APPENDIX C

Derivation of Interest Rate of Savings and Price of Financial Innovators

By substituting K from equation (18); $S_t = \frac{\beta}{1+\beta} w$ and $\dot{\tau} = \left(F \tau^{\phi} \right)^{\frac{-1}{\lambda - 1}} \left(\frac{w}{\lambda P_{\dot{\tau}}} \right)^{\frac{\lambda}{\lambda - 1}}$ into equation (12) and rearranging

parameters, the profit maximization problem of financial intermediations becomes:

$$\max_{\gamma_S, P_{\dot{\tau}}} \gamma_K \frac{\beta}{1+\beta} \left(\frac{1}{\lambda} \right)^{\frac{\lambda}{\lambda - 1}} \frac{\left(F \tau^{\phi} \right)^{\frac{1}{1-\lambda}} w^{\frac{2\lambda - 1}{\lambda - 1}}}{\delta} P_{\dot{\tau}}^{\frac{\lambda}{1-\lambda}} - \gamma_S \frac{\beta}{1+\beta} w - \left(F \tau^{\phi} \right)^{\frac{1}{1-\lambda}} \left(\frac{w}{\lambda} \right)^{\frac{\lambda}{\lambda - 1}} P_{\dot{\tau}}^{\frac{1}{1-\lambda}}.$$

The first derivative with respect to $P_{\dot{\tau}}$ indicates $P_{\dot{\tau}} = \frac{\lambda}{\delta} \frac{\beta}{1+\beta} \gamma_K w$.

APPENDIX D

Derivation of Wage of Labor and Interest Rate of Capital for Firms

As mentioned in the *Appendix A*, the wage in the economy is equal in every sector:

$$w_\tau = w_Y = w.$$

By substituting the function of Y into the profit-maximizing problem and replacing $w_Y = w$ the profit maximization becomes:

$$\max_{w, \gamma_K} A K^{\alpha} L_Y^{D1-\alpha} - w L_Y^D - \gamma_K K. \tag{D1}$$

Given $K = \frac{\beta}{1+\beta} \left(\frac{1}{\lambda} \right)^{\frac{\lambda}{\lambda - 1}} \frac{\left(F \tau^{\phi} \right)^{\frac{1}{1-\lambda}} w^{\frac{2\lambda - 1}{\lambda - 1}}}{\delta} P_{\dot{\tau}}^{\frac{\lambda}{1-\lambda}}$. Then, substitute $P_{\dot{\tau}} = \left[\frac{\beta}{1+\beta} \frac{\lambda}{\delta} \right] \gamma_K w$ into the function of K, obtaining:

$$K = \left(\frac{1+\beta}{\beta} \frac{\delta}{F \tau^{\phi}} \right)^{\frac{1}{\lambda - 1}} \lambda^{\frac{2\lambda}{\lambda - 1}} w \gamma_K^{\frac{\lambda}{1-\lambda}}.$$

We also have $L_Y^D = 1 - \left(\frac{1+\beta}{\beta}\frac{\delta}{F\tau^{\phi}}\right)^{\frac{1}{\lambda-1}} \lambda^{\frac{2}{1-\lambda}} \gamma_K^{\frac{1}{1-\lambda}}$.

We set $Z = \left(\frac{1+\beta}{\beta}\frac{\delta}{F\tau^{\phi}}\right)^{\frac{1}{\lambda-1}}$; the function of K and L_Y^D becomes:

$$K = Z\lambda^{\frac{2\lambda}{\lambda-1}} w\gamma_K^{\frac{\lambda}{1-\lambda}}, \tag{D2}$$

$$L_Y^D = 1 - Z\lambda^{\frac{2}{1-\lambda}} \gamma_K^{\frac{1}{1-\lambda}}. \tag{D3}$$

By substituting equation (D2) and (D3) into (D1), the objective function now becomes:

$$\max_{w,\gamma_K} A\left[Z\lambda^{\frac{2\lambda}{\lambda-1}} w\gamma_K^{\frac{\lambda}{1-\lambda}}\right]^{\alpha}\left[1 - Z\lambda^{\frac{2}{1-\lambda}}\gamma_K^{\frac{1}{1-\lambda}}\right]^{1-\alpha} - w\left[1 - Z\lambda^{\frac{2}{1-\lambda}}\gamma_K^{\frac{1}{1-\lambda}}\right] - \gamma_K Z\lambda^{\frac{2\lambda}{\lambda-1}} w\gamma_K^{\frac{\lambda}{1-\lambda}}.$$

The objective function is rewritten as follow:

$$\max_{w,\gamma_K} A\left[Z\lambda^{\frac{2\lambda}{\lambda-1}} w\gamma_K^{\frac{\lambda}{1-\lambda}}\right]^{\alpha}\left[1 - Z\lambda^{\frac{2}{1-\lambda}}\gamma_K^{\frac{1}{1-\lambda}}\right]^{1-\alpha} - w + wZ\lambda^{\frac{2}{1-\lambda}}\gamma_K^{\frac{1}{1-\lambda}} - Z\lambda^{\frac{2\lambda}{\lambda-1}} w\gamma_K^{\frac{1}{1-\lambda}}.$$

The first derivative with respect to w indicates:

$$w = (A\alpha)^{\frac{1}{1-\alpha}}\left[1 - Z\lambda^{\frac{2}{1-\lambda}}\gamma_K^{\frac{1}{1-\lambda}}\right]\left[Z\lambda^{\frac{2\lambda}{\lambda-1}}\gamma_K^{\frac{\lambda}{1-\lambda}}\right]^{\frac{\alpha}{1-\alpha}}\left[1 + Z\gamma_K^{\frac{1}{1-\lambda}}\left(\lambda^{\frac{2\lambda}{\lambda-1}} - \lambda^{\frac{2}{1-\lambda}}\right)\right]^{\frac{1}{\alpha-1}}. \tag{D4}$$

The first derivative with respect for γ_K indicates:

$$w = \left[\frac{1 - Z\lambda^{\frac{2}{1-\lambda}}}{Z\lambda^{\frac{2\lambda}{\lambda-1}}}\right]^{\frac{\alpha}{\alpha-1}} \gamma_K^{\frac{\alpha}{(1-\lambda)(\alpha-1)}}\left[\frac{Z\lambda^{\frac{2\lambda}{\lambda-1}} - Z\lambda^{\frac{2}{1-\lambda}}}{\left(A\alpha\lambda\gamma_K^{-1}\right) - \left(A\alpha Z\lambda^{\frac{3-\lambda}{1-\lambda}}\gamma_K^{\frac{\lambda}{1-\lambda}}\right) + \left(A(1-\alpha)Z\lambda^{\frac{2}{1-\lambda}}\gamma_K^{\frac{\lambda(1+\alpha)}{1-\lambda}}\right)}\right]^{\frac{1}{\alpha-1}}. \tag{D5}$$

To simplify the analysis, this model assumes $\alpha = 0.5$ and $\lambda = 0.5$. The function of w and γ_K as equation (D4) and (D5) now become:

$$w_1 = \frac{2A^2 Z\gamma_{K1} - 0.125Z\gamma_{K1}^3}{\left[\frac{63}{16}Z\gamma_{K1}^2 + 1\right]^2},$$

$$w_2 = \frac{256}{3969}\frac{\left(0.5^5 AZ\gamma_{K2}^{5/2} - 0.5^6 AZ\gamma_{K2}^2 + 0.25A\right)^2}{\gamma_{K2}^4\left(Z - 0.5^4 Z^2\right)}.$$

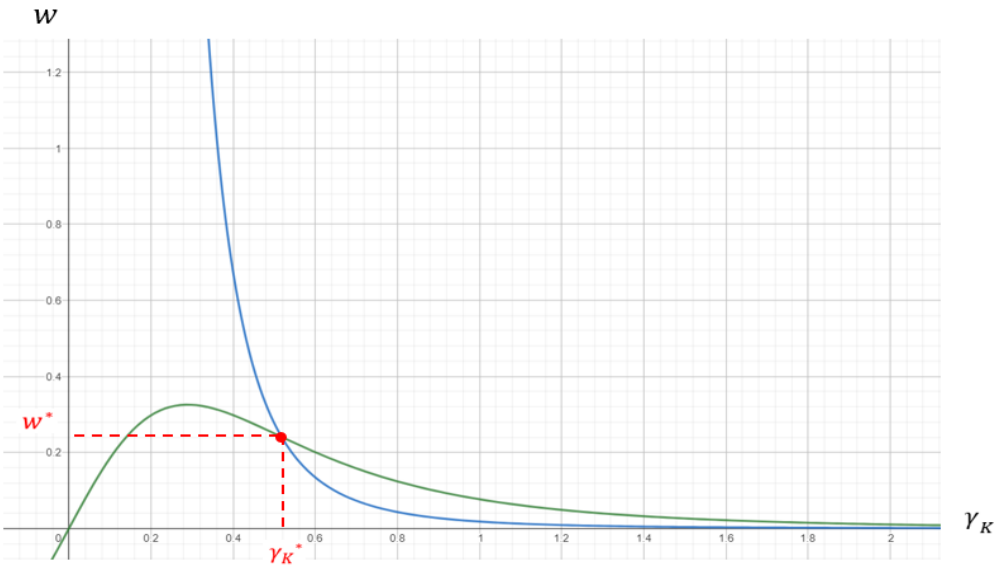

Fig. 2. **The Equilibrium of Wage of Labor and Interest Rate of Borrowed Capital**

Source: Compiled by the authors.

Figure 2 illustrates the wage of labor and interest rate of borrowed capital at the equilibrium through determining the curve of w_1 (green line) and w_2 (blue line). At the intersection of w_1 and w_2, the value of w^* and $\gamma_K{}^*$ would be settled. By doing that, this model can find the solution of wage (w) and the interest rate for loans (γ_K). Also, determining w^* and $\gamma_K{}^*$ confirms the existence and validity of the economy we constructed.

Translated by N.I. Sokolova