International RD Funding and Patent Collateral in an RD-Growth Model

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Abstract

This paper develops an R&D-based growth model featuring international R&D funding and patent collateral. It then uses the model to examine how the international borrowing interest rate and the fraction of patent collateral will affect innovations and economic growth.

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1. Introduction

This paper develops an R&D-based growth model that features international R&D funding and patent collateral. Our purpose is to examine how the international borrowing interest rate and the fraction of patent collateral will affect innovations and economic growth. This paper is motivated by the following two observations.

Firstly, the financing of business enterprise R&D from abroad is observed in OECD data. It is commonly believed that R&D funding is critical for the growth effect of R&D investment. In their recent paper, based on empirical data, Aghion et al. (2012) find that, by virtue of credit and liquidity constraints, R&D is more affected by countercyclical monetary policy than by physical investment. To reflect this fact, Chu and Cozzi (2014) set up a Schumpeterian growth model that features the cash-in-advance (CIA) constraint on R&D investment. A notable specification in their model is that R&D entrepreneurs fully fund their activities from the home country. However, according to the practical data, OECD (2011, p. 92) documents the following statement. "On average, R&D funding from abroad plays quite an important role in the funding of business R&D. In the EU, it represented around 10% of total business enterprise R&D in 2008. … For Austria, Ireland, the Slovak Republic and the United Kingdom, funds from abroad represented 20% or more of total business enterprise R&D."[1] As is obvious, the Chu and Cozzi (2014) specification ignores the fact that R&D companies obtain a considerable portion of their R&D funding from abroad.

Secondly, the financing of business enterprise R&D is observed to be subject to patent collateral. A significant number of empirical studies point

[1] See OECD (2011, p. 92) for the real values of R&D funds from abroad in OECD countries.

out that R&D patents often serve as collateral when entrepreneurs issue bonds to borrow funds for R&D (see, e.g., Brown et al., 2012; Mann, 2014; Hochberg et al., 2014). Based on these empirical findings, it is interesting to shed light on how patent collateral provides a vehicle to affect R&D investment and economic growth.

Up till now, to the best of our knowledge, no theoretical analysis has been devoted to dealing with international R&D funding and patent collateral in an R&D-based model. This paper seeks to fill this gap.[2] Two main findings emerge from the analysis. First, a rise in the fraction of patent collateral is beneficial to both innovations and economic growth. Second, a rise in either the foreign interest rate or the fraction of borrowed R&D funding is harmful to innovations and economic growth.

2. The model

We set up an R&D growth model featuring international R&D funding patent collateral in R&D firms. In what follows, we will briefly describe the economy's structure.

2.1 Households

Consider an economy that is populated by a large number of identical and infinitely-lived households. The lifetime utility of the representative household is given by:

$$\int_0^\infty (\ln C)\, e^{-\rho t} dt\,;\ \rho > 0\,, \tag{1a}$$

[2] In their open-economy R&D-growth models, Aghion et al. (2005) and Chu et al. (2016) build up a distance-to-frontier R&D-based growth model, in which R&D entrepreneurs are subject to credit constraints rather than patent collateral constraints. However, these studies stress that the backward country's innovations would make its growth rate converge to the leading country's *exogenous* growth rate. This paper instead examines how international R&D funding and the international borrowing interest rate will affect the *endogenous* growth rate.

where C is the consumption of final goods, and ρ is the subjective discount rate. The total labor supply of each household is fixed at the level L. Thus, the household's budget constraint can be expressed as:

$$\dot{K}+\dot{a}=rK+\left(r_A+\dot{V}/V\right)a+wL+rB-C\,, \tag{1b}$$

where K is the stock of physical capital, $a(=VA)$ is the value of equity shares (R&D stocks), A is the number of equity shares (i.e., the number of varieties of intermediate goods), V is the value of an invented variety, r is the interest rate of the home country, r_A is the rate of dividends, $\dot{V}/V$ is the rate of capital gain or loss in equity shares, w is the wage rate,[3] and B is the amount of loans lent to R&D firms. The no-arbitrage condition between holding physical capital and equity shares is $r=r_A+\dot{V}/V$.

The usual Keynes-Ramsey rule is:

$$\frac{\dot{C}}{C}=r-\rho\,. \tag{2}$$

2.2 Final goods

The domestic final goods Y are treated as the numéraire. They are produced by competitive firms using labor and a continuum of intermediate goods in the form:

$$Y=L_Y^{1\text{-}\alpha}\int_0^A x_i^{\alpha}di\,, \tag{3}$$

where L_Y is the labor input in the production of final goods, x_i represents the intermediate goods for $i\in[0,A]$, and A is the number of varieties of intermediate goods.

Let p_i be the price of x_i. The profit function of the final good firms

[3] We assume that workers are perfectly mobile across sectors. This implies that a unified wage rate w is present in the domestic economy.

can then be written as:

$$\pi_Y = Y - wL_Y - \int_0^A p_i x_i di \,, \tag{4}$$

Therefore, the conditional demand functions for L_Y and x_i are:

$$L_Y = \frac{(1-\alpha)Y}{w}, \tag{5}$$

$$x_i = L_Y \left(\frac{\alpha}{p_i}\right)^{\frac{1}{1-\alpha}}. \tag{6}$$

2.3 Intermediate goods

There is a continuum of differentiated intermediate goods, and each intermediate good firm is owned by a monopolist. Following Romer (1990), physical capital is the factor input used to produce intermediate goods, and one unit of capital produces one unit of intermediate good. The production function can then be expressed as $x_i = k_i$, where k_i is the capital input used by the type-i intermediate firm. Therefore, the monopolistic profit is $\pi_{x_i} = p_i x_i - rk_i$. Accordingly, the profit-maximizing pricing of the type-i firm is $p_i = r/\alpha$, which implies that the decisions of all intermediate good firms are symmetric. Thus we can drop the notation i for variables $\{x, p, k, \pi_x\}$. The profit function can then be represented as:

$$\pi_x = (\frac{1-\alpha}{\alpha})\, rx \,. \tag{7}$$

2.4 R&D

In the R&D sector, the value of any variety V is equal to $V = \int_t^\infty \pi_x e^{-r(\tau - t)} d\tau$. This implies that V follows the no-arbitrage condition:

$$rV = \dot{V} + \pi_x \,. \tag{8}$$

The return on investment in R&D will be equal to the profit from the monopolistic intermediate good firm π_x plus the capital gain $\dot{V}$. In line with Romer (1990), the R&D firm hires R&D labor L_A to produce new varieties of the knowledge-driven form $\dot{A} = \varsigma A L_A$, where the parameter ς reflects the R&D productivity.[4]

In each period, the R&D firm needs working capital to pay for a fraction of the labor costs θ in advance, where $\theta \in [0,1]$. The total wage payment for the R&D labor is wL_A, and hence the R&D firm needs to borrow the amount of funds $\theta w L_A$. In this economy, the R&D firm can choose to fund the shortage of working capital from both the foreign and home countries. Let ε be the proportion of the shortage of working capital borrowed from foreign countries, where $\varepsilon \in [0,1]$. Moreover, to reflect the empirical fact that R&D funding from abroad plays quite an important role in the funding of business R&D, we assume that the foreign country interest rate is lower than the home country interest rate, that is, $\overline{r} < r$.[5] Therefore, the rational R&D firm tends to borrow as much as possible from foreign countries. However, it is not possible for the R&D firm to borrow without limit from foreign countries, because it should offer the market value of its patents as collateral. Let ϕ denote the fraction of the collateral, where $\phi \in [0,1]$.[6] The patent collateral constraint can then be expressed as:

[4] Our analytical results in Section 3 remain unchanged when the R&D firm uses final goods to produce new varieties in the lab-equipment form. To save space, the detailed derivations are not reported here but are available from the authors upon request.

[5] To simplify our analysis, we assume that the home country is a small open economy, and in line with Turnovsky (1996), the foreign interest rate is treated as given.

[6] We consider that R&D firms finance the shortage of working capital by way of international borrowings. In line with Hochberg et al. (2014), R&D firms are allowed to issue the venture debt to the home country or to foreign countries. We assume that the international funding market is an asymmetric information market. Therefore, to avoid lending risk, foreign lenders will ask the home country's R&D firms to provide some collateral.

$$\varepsilon\theta w L_A \le \phi V\dot{A}. \tag{9}$$

Due to $r > \bar{r}$, the profit-maximizing R&D firm will choose a value of ε such that the inequality constraint (9) is binding.[7] Accordingly, the remaining proportion of the shortage of working capital is funded from the home households, i.e., $B = (1-\varepsilon)\theta w L_A$.

Let π_A denote the profit of the R&D firm. The R&D firm's maximization problem can be written as:

$$Max \quad \pi_A = V\dot{A} - wL_A - \theta[(1-\varepsilon)r + \varepsilon\bar{r}]wL_A, \tag{10a}$$

$$s.t. \quad \dot{A} = \varsigma A L_A \text{ and } \varepsilon\theta w L_A = \phi V\dot{A}. \tag{10b}$$

The free entry condition for R&D and the optimum condition for ε are given by:

$$V = \{1 + \theta[(1-\varepsilon)r + \varepsilon\bar{r}]\}\frac{w}{\varsigma A}, \tag{11a}$$

$$\varepsilon = \frac{\varsigma\phi}{\theta}\frac{VA}{w}. \tag{11b}$$

2.5 Market clearing and aggregation

The market-clearing condition for the labor market is:

$$L_Y + L_A = L. \tag{12}$$

With its symmetric feature, the market-clearing condition for physical capital is expressed as: $\int_0^A x_i di = Ax = Ak = K$, where Ak is the aggregate capital demand for all intermediate firms and K is the supply of capital provided by the households. Moreover, the home country's resource constraint can be expressed as $Y = \dot{K} + C + \bar{r}\varepsilon\theta w L_A$.

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[7] Equation (9) indicates that only the international borrowings of the R&D firm are subject to the patent collateral constraint. Our analytical results are robust when domestic borrowings are also subject to the patent collateral constraint.

3. Analysis

Along the balanced growth path, since the allocations of labor and the domestic interest rate are stationary, we can infer that both $x = L_Y(\frac{\alpha^2}{r})^{\frac{1}{1-\alpha}}$ and $\pi_x = (\frac{1-\alpha}{\alpha})rx$ remain intact at a fixed value. As a result, it is clear that $V = \int_t^{\infty} \pi_x e^{-r(\tau - t)} d\tau = \pi_x / r$ also remains intact at a fixed value, thereby implying that $\dot{V} = 0$ in the steady-state equilibrium.

From (5), (8), $A\pi_x = \alpha(1-\alpha)Y$,[8] (11a), and (11b), we have:

$$\theta r^2 + \left[(1 - \phi\alpha\varsigma L_Y\right]r - \left(1 - \phi\overline{r}\right)\alpha\varsigma L_Y = 0 . \tag{13}$$

At the balanced growth equilibrium, $\dot{A}/A = \dot{C}/C$ holds. Then, by using $\dot{A}/A = \varsigma L_A$, $\dot{C}/C = r - \rho$, and the labor market-clearing condition, $L_Y + L_A = L$, we obtain:

$$L_Y = L - \left(\frac{r-\rho}{\varsigma}\right). \tag{14}$$

Substituting (14) into (13) yields:

$$(\phi\alpha + \theta)r^2 + \left[1 - \phi\alpha\left(\varsigma L + \rho\right) + \alpha\left(1 - \phi\overline{r}\right)\right]r - \alpha\left(1 - \phi\overline{r}\right)\left(\varsigma L + \rho\right) = 0 . \tag{15}$$

We can solve for two values of r to satisfy (15). One is positive and the other one is negative. To make the analysis meaningful, we exclude the negative interest rate. Therefore, the reasonable equilibrium value of the domestic interest rate is (a tilde over the variable denotes its steady-state value):

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[8] Based on equation (6) with the symmetric feature $p = p_i$, we have $Apx = \alpha Y$. Moreover, by using (7), the aggregate profits of all intermediate firms can be expressed as $A\pi_x = [(1-\alpha)/\alpha]\, rAx$. By inserting $p = r/\alpha$ and $Apx = \alpha Y$ into $A\pi_x = [(1-\alpha)/\alpha]\, rAx$, we have $A\pi_x = \alpha(1-\alpha)Y$.

$$\tilde{r} = \frac{-\Phi + \sqrt{\Phi^2 + 4\alpha(\phi\alpha+\theta)\left(1-\phi\bar{r}\right)\left(\varsigma L+\rho\right)}}{2(\phi\alpha+\theta)} > 0 \,, \tag{16}$$

where $\Phi \equiv \left[1-\phi\alpha\left(\varsigma L+\rho\right)+\alpha\left(1-\phi\bar{r}\right)\right]$. From (2) and (16), we can derive the balanced growth rate as follows:

$$\tilde{g} = \frac{-\Phi + \sqrt{\Phi^2 + 4\alpha(\phi\alpha+\theta)\left(1-\phi\bar{r}\right)\left(\varsigma L+\rho\right)}}{2(\phi\alpha+\theta)} - \rho \,. \tag{17}$$

Differentiating (17) with respect to ϕ, $\bar{r}$, and θ yields the following results:

$$\frac{\partial \tilde{g}}{\partial \phi} = \frac{\alpha\varsigma L_Y(\tilde{r}-\bar{r})}{2(\phi\alpha+\theta)\tilde{r}+\Phi} > 0 \,, \tag{17a}$$

$$\frac{\partial \tilde{g}}{\partial \bar{r}} = \frac{-\alpha\phi\varsigma L_Y}{2(\phi\alpha+\theta)\tilde{r}+\Phi} < 0 \,, \tag{17b}$$

$$\frac{\partial \tilde{g}}{\partial \theta} = \frac{-\tilde{r}\left[\phi\alpha(\varsigma L+\rho)+(1-\varepsilon)\theta\right]}{\left[2(\phi\alpha+\theta)\tilde{r}+\Phi\right](\phi\alpha+\theta)} < 0 \,, \tag{17c}$$

where $2(\phi\alpha+\theta)\tilde{r}+\Phi > 0$.[9] The results in (17a)-(17c) lead us to establish the following proposition:

Proposition 1. *A rise in the fraction of the collateral (ϕ) raises the balanced growth rate, while a rise in either the foreign interest rate ($\bar{r}$) or the fraction of borrowed R&D labor costs (θ) lowers the balanced growth rate.*

The economic intuition behind Proposition 1 is quite obvious. A higher fraction of the collateral (ϕ) implies that the home country's R&D firms can obtain a larger amount of cheaper funds from foreign countries. This encourages the R&D firm to hire more labor, and hence leads to more innovations and higher economic growth. Similarly, in response to a higher

[9] From equation (16), we have $2(\phi\alpha+\theta)\tilde{r}+\Phi = \sqrt{\Phi^2 + 4\alpha(\phi\alpha+\theta)\left(1-\phi\bar{r}\right)\left(\varsigma L+\rho\right)}$. Given $1>\phi>0$ and $1>\bar{r}>0$, we can infer $\Phi^2 + 4\alpha(\phi\alpha+\theta)\left(1-\phi\bar{r}\right)\left(\varsigma L+\rho\right) > 0$. This implies that $2(\phi\alpha+\theta)\tilde{r}+\Phi > 0$ holds.

foreign interest rate ($\overline{r}$) or a higher fraction of borrowed R&D labor costs (θ), the R&D firm is motivated to reduce its R&D labor. This in turn leads to a decline in the home country's innovations and economic growth.

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