(In)Determinacy, Bargaining, and R&D Policies in an Economy with Endogenous Technological Change

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Abstract

In this paper, the author shows how the introduction of a bargaining game structure into a standard R&D endogenous growth model can be a potential source of local indeterminacy. He also shows that on a high-growth path, the government, by directly engaging in R&D activities and using R&D subsidies, may not enhance economic growth. On a low-growth path, the government, by directly engaging in R&D activities and using R&D subsidies, may enhance economic growth.

Keywords: government R&D, innovation, endogenous growth, bargaining, indeterminacy

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1.   Introduction

The role of the government cannot be ignored in the endogenous growth model, and accordingly in the 1990s there was an explosion of research on the growth effects of several government activities. Such studies have emphasized the important role of private sector research and development. In the R&D-driven endogenous growth models, Romer (1990), Aghion and Howitt (1992), and Barro and Sala-i-Martin (2004) all find that R&D subsidies encourage firms to devote more resources to R&D activities and as a result there is an increasing rate of economic growth in the long run. Jones and Williams (1998, 2000) point out that the decentralized economy typically under-invests in R&D when compared to what is socially optimal when using data for the US economy. The reason for this, they claim, is that monopoly pricing and knowledge spillovers may result in too little private R&D. Besides subsidizing R&D, one point, which is very important, is that the government also engages in R&D activities.

The public sector is a major part of a nation's research system. For example, in the process of economic development in Taiwan, the government has played a leading role in investing in R&D in science and technology, such as through the establishment of public research organizations (i.e., Academia Sinica and the Industrial Technology Research Institute). These institutes research the blueprints, technology, or new production processes in many fields, and transfer them to private industries in order to produce the new products. Glomm and Ravikumar (1994), for instance, present a model in which the economy grows thanks to public research. Pelloni (1997) allows the government to invest in public research so as to improve the growth performance of the economy. Park (1998) indicates that the share of the research conducted by the government varies across countries and is generally higher among smaller R&D nations (that is, among nations with smaller R&D to GDP ratios). Park (1998) also introduces public research to a model that expands the variety of products in Romer (1990) in order to analyze the impact of government research on long-run growth. Morales (2004) finds that the basic research performed by public institutions has unambiguously positive effects on growth, and points out that the engagement in applied research by public institutions could have negative growth effects. Clearly, a better understanding of growth, if it leads to the design of policies that stimulate growth, can have a significant impact on the standard of living. What, then, are the consequences for long-term growth and R&D? For this reason, in this paper we introduce not only an R&D subsidy policy, but also government R&D in cases where there are too few private R&D activities in a decentralized economy. We describe the role played by government in technological progress in the economic development of a country.

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In endogenous growth models, indeterminacy can take the form of multiple balanced growth paths along which the economy can persistently grow in the long run. Lucas (1993) indicates why two different countries, such as South Korea and the Philippines, whose initial conditions were so close, have subsequently differed so much in their later growth performance. Indeterminacy may explain why fundamentally similar economies can exhibit the same per capita income but grow at different rates. Some studies have discussed the sources of indeterminacy, such as imperfect competition (Gali and Zilibotti, 1995; etc.), externalities (Benhabib and Perli, 1994; etc.), investment adjustment costs (Lai and Chin, 2010; etc.) and other government policies (Park and Philippopoulos, 2004; etc.). All such studies adopt the AK growth model. However, an economy with a high growth rate of output per worker has also had a high rate of technological progress (see Table 12-2, Blanchard, 2011). Therefore, the present R&D-driven growth models are found to exhibit indeterminacy. See, for example, Haruyama and Itaya (2006) and Arnold and Kornprobst (2008), who show that indeterminacy may arise in R&D-based growth models when the elasticity of intertemporal substitution is greater than one. In addition, while Chen and Chu (2010) refer to the literature on patent policy and economic growth, they do not include a vertically-connected imperfectly competitive market structure. The present R&D-driven growth model is characterized by either imperfect competition in the intermediate goods market or imperfect competition in the final goods market. In a vertically-connected imperfectly competitive market, for example, in the case of a model of R&D in an upstream industry that expands the variety of products and monopolistic competition in the downstream industry, there is no literature that discusses the interaction between the upstream and downstream industries that influences the economic fundamentals and that in turn presents an indeterminate equilibrium. Therefore, this paper investigates the possibility of a multiplicity of BGPs, in conjunction with the indeterminacy of transitional dynamics, when it proceeds to incorporate bargaining between final goods firms and intermediate goods firms with endogenous technological change that leads to long-run growth.

It is feasible for upstream and downstream firms to negotiate with each other in their own interests.[1] Some studies look at bargaining in a vertically-connected market structure. For instance, by using data on yogurt sold in a large urban area of the US, Villas-Boas (2007) finds that wholesale prices appear to be close to marginal cost and retailers wield significant pricing power in this vertical chain. This is consistent with

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[1] Bester (1993) mentions that "in many markets prices are the outcome of bilateral negotiations, so that both the seller and the buyer take an active part in setting the price. Examples include not only the bazaar of a less developed nation, but also the market for used cars, real estate, antiques, and inputs for manufacturing firms".

the non-linear pricing scheme of manufacturers or retailers with high bargaining power. Acemoglu et al. (2010) use a micro-data set of all British manufacturing plants between 1992 and 2001 to investigate vertical integration in the U.K. manufacturing sector. They find that the relationship between a downstream industry and an upstream industry is more likely to be a vertically-integrated one. Tirole (1998) refers to the traditional franchise contract in which the upstream firm offers the contract and the downstream firm accepts the contract. In real life, however, it is often the case that the bargaining contract itself is not completely exogenous, for people may have to choose a protocol in the process of reaching an agreement. This paper thus introduces an equally popular and important bargaining model, namely, the Nash (1950) bargaining model, to analyze the franchise contract bargaining that takes place between the intermediate goods firms and the final goods firms, since final goods firms prefer to negotiate to lower the prices of intermediate goods to reduce their cost. On the other hand, intermediate goods firms prefer to extract more rent from the downstream industry. Thus these firms also have incentives to engage in contract bargaining. While both the final goods and intermediate goods firms are bound to perform their duties in relation to the contractible activities, they are free to choose how much they will produce in terms of the noncontractible activities (Antras and Helpman, 2007). In terms of the present R&D-based growth model, there is only one study (Wang et al., 2010) that investigates contract bargaining between the final and intermediate goods producers by extending Benassy (1998). However, it lacks dynamic analysis and the role played by the government in R&D activities in a complete macro model. This paper follows the bargaining structure of Wang et al. (2010) in a successively imperfectly competitive market, and looks into whether the bargaining between final and intermediate goods firms causes local dynamic indeterminacy. To set up a bargaining structure between final goods and intermediate goods firms requires a more general model format than the traditional R&D-driven growth model. There is, to the best of our knowledge, no study that indicates that the source of the indeterminacy is the bargaining power. In our model, it can be clearly observed that once the final goods firms have no bargaining power, the model reverts back to the traditional model. Moreover, this paper derives an important result in that it states that the bargaining power may be the source of indeterminacy in an economy.

This paper focuses on the financial resources that come in the form of subsidies out of government revenue. The type of government revenue that we consider is a specific tax that is imposed on both final goods and intermediate goods to finance the subsidies and expenditure on R&D activities. This is because ad valorem taxation (a tax proportional to the firm's revenue/profit) leads to a lower consumer price of a good even though firms would exit the market in a monopolistic competition case

(Schröder, 2004). It is well known that the number of intermediate goods firms in a market characterized by monopolistic competition is a key point in R&D-driven endogenous growth models because the more firms that there are in the intermediate goods market, namely, the more variety there is, the more the economy grows. If the ad valorem taxation leads the firms to exit the market, economic growth will be harmed. On the other hand, Kitahara and Matsumura (2006) investigate how a specific tax and an ad valorem tax affect the equilibrium location choice in a model of product differentiation which encompasses the Hotelling and Vickrey-Salop spatial models. They find that the specific tax does not affect the firms' equilibrium location, their output quantities, or their profits. Therefore, a specific tax is a good tool for the government to generate revenue in an R&D growth economy. Hence, for the R&D-driven endogenous growth model, we introduce a specific tax to analyze how the government's R&D policies (the government engages in R&D activities and subsidizes the R&D cost of the firms) affect the rate of economic growth.

We present a four-stage model. In the first stage, the government levies specific taxes on final goods and intermediate goods to finance its expenditure, to engage in R&D activities and to subsidize the R&D costs of the firms. In the second stage, the final goods firms and the intermediate goods firms bargain over the franchise contract including over the franchise fee and the prices of the intermediate goods according to Nash efficient bargaining. In other words, the upstream and downstream industries will vertically integrate their operations to eliminate double marginalization through the franchise contract. In the third stage, the final goods firms determine the prices of the final goods to maximize their profits. In the fourth stage, the consumers decide on the expenditure plan to maximize their utility. We proceed by solving the model backwards.

2.   The model

The model is an extension of an endogenous growth model with an expanding-variety growth model (Romer lab-equipment model) and the bargaining structure of Wang et al. (2010) in a successively imperfectly competitive market. We consider that the government not only implements a tax/subsidy policy but also engages in R&D activities and in an imperfectly competitive final goods market. There are five agents in this model, namely, R&D firms, the intermediate goods firms, the final goods producers, the government and households. In this model, R&D investment creates new types of intermediate goods for final production. The prices of intermediate goods are determined by the negotiations between the intermediate goods firms and final goods firms. The government levies a specific tax to finance the subsidy for too little R&D and engages in R&D activities. The household chooses a

consumption/investment plan.

2.1 R&D

The R&D technology is such that, to develop a new idea, a researcher needs a quantity of labor to develop ideas. The production function in the R&D sector is given by

$$\dot{n} = nL_A \tag{1}$$

where L_A is the amount of labor hired in the R&D sector which is from the R&D firms (L_R) and the government sector (L_G), both the government and private firms are engaged in R&D, $L_A = L_R + L_G = vL_A + (1-v)L_A$, v is the proportion of labor employed in the R&D sector between the R&D firms and the government, $\dot{n}$ is the number of new blueprints created for a given period of time, and n refers to the positive spillovers in the production of blueprints. The more workers the R&D sector employs or the more varieties of goods the intermediate goods market has, the more new blueprints that are produced per unit of time.[2]

The research sector's after-subsidy profit flow is given by

$$\pi_A = p_A \dot{n} - (1-s)wvL_A \tag{2}$$

where p_A is the after-subsidy cost or value of a new blueprint $\dot{n}$, s is a fraction of all research expenses paid by the government, and w is the wage rate which is common to all sectors in the economy since labor is assumed to be perfectly mobile. Such a subsidy to R&D lowers the private cost.

2.2 Intermediate goods market

The typical intermediate goods firm produces its differentiated goods with a technology that requires one unit of labor per unit of intermediate goods ($x_i = l_i^x$).

Each intermediate goods firm produces and sells a slightly unique variety of goods x_i to each final goods firm to maximize its profit since the good is protected by an infinitely-lived patent, taking the actions of all other producers in the intermediate goods sector as given

$$\pi_i = m(p_i^x x_i - w l_i^x) + m f_i \tag{3}$$

where l_i^x is the amount of labor used by firm i, p_i^x is the price of the intermediate goods, m represents the number of final goods firms, and f_i is the franchise fee received from the final goods firm.[3]

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[2] To simplify our notation, the time arguments will all be dropped.
[3] To simplify the analysis, we assume that the fee paid to intermediate goods firms is identical to those in all contracts.

2.3 Final goods

We consider a production economy with imperfectly competitive product markets. The consumption goods are produced by monopolistically competitive firms. Each consumption good is supposed to be produced by a single firm, that is, m also represents the number of firms which produce industry j goods. Therefore, a composite final good Y can be represented as

$$Y \equiv m\left(\frac{1}{m}\int_{j=0}^{m} y_j^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}, \quad \sigma > 1 \tag{4}$$

where σ is the constant elasticity of substitution. Each firm produces y_j by using a continuum of intermediate goods x_i. According to Dixit and Stiglitz (1977), the production function of firm j is

$$y_j \equiv \left(\int_0^n x_{ij}^{\frac{1}{\alpha}} di\right)^{\alpha}, \quad \alpha > 1 \tag{5}$$

where $i \in [0, n(t)]$ is the range of intermediate goods existing at time t. $-1/(1-\alpha)$ represents the elasticity of substitution between intermediate goods.

The producer j in the final goods sector chooses a price to maximize its profit

$$\Pi_j = q_j\left(\int_0^n x_{ij}^{\frac{1}{\alpha}} di\right)^{\alpha} - \int_0^n \hat{p}_{ij} x_{ij} di - \int_0^n f_{ij} di \tag{6}$$

where q_j is the price of the final goods, $\hat{p}_{ij}$ is the after-tax price of the intermediate goods i, and f_{ij} represents the franchise fee that the final goods producer j has to pay to the intermediate goods firms in order to obtain the right and know-how to produce the final good by using these intermediated goods.

We assume that the government levies a specific tax on each final good and intermediate good, and that each tax is symmetric over time for analytical simplicity. The consumption goods price and the intermediate goods price become

$$p_j = q_j + \tau_y \tag{7}$$

$$\hat{p}_{ij} = p_{ij}^x + \tau^x \tag{8}$$

where p_j is the after-tax price of consumption good j, τ_y represents the specific tax imposed on the final goods and is the same for all j, and τ^x represents the

specific tax imposed on the intermediate goods i and is the same for all i.

2.4 Government

The government cannot borrow and thus satisfies the budget constraint

$$T_y + T^x = S + G \tag{9}$$

where $T_y = m\tau_y \left(\int_0^n x_{ij}^{\frac{1}{\alpha}} di \right)^{\alpha}$ and $T^x = m\tau^x \int_0^n x_i di$ are total tax revenues from final goods and intermediate goods markets, $S = vswL_A$ is the subsidy to defray the R&D cost of the firms, and $G = (1-v)wL_A$ is government expenditure to employ labor in the R&D sector. In considering the decomposition of government expenditures from the final and intermediate goods firms, T_y, and T^x, we assume

$$T_y = g(1 - v(1-s))wL_A \tag{10}$$

$$T^x = (1-g)(1 - v(1-s))wL_A \tag{11}$$

where the parameter $0 < g < 1$ is the share of government expenditure financed by tax revenues from the final goods market and $1-g$ is the share of the government expenditure financed by tax revenues from the intermediate goods market. Since we would like to analyze how, once the government controls the R&D policy parameters, the economy responds in terms of performance, we assume that the parameters (g, s, v) are fixed and that the vector of tax rates is adjusted endogenously.[4] This will allow our results to easily show how the government's R&D subsidy policy and the government's R&D activities affect the dynamics of growth.

2.5 Households

The individuals inelastically supply labor service, L. Consumption loans are extended in both competitive labor and imperfectly competitive product markets. The representative household's preferences are defined over an infinite horizon

$$V = \int_0^{\infty} e^{-\rho t} U(\ln C dt \tag{12}$$

where

$$U(C) = \ln C \tag{13}$$

Eq. (12) indicates that utility is a unitary elasticity function and is discounted by a constant pure rate of time preference ρ.

The budget constraint, which describes how the household invests the new assets,

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[4] Please refer to Zeng and Zhang (2007, Journal of Economic Dynamics & Control), and Peretto (2007, Journal of Economic Theory).

is equal to the rate of return r earned on assets and total labor income plus the profit the household receives from the downstream firms minus total spending on consumption goods. It is therefore given by

$$\dot{a} = ra + wL + m\Pi - E \tag{14}$$

where

$$E = PC = \int_{j=0}^{m} p_j c_j dj \tag{15}$$

E is total spending on consumption goods, and P is the aggregate consumption price index. a represents the household assets, which is the value of the stock of the blueprints, $a = p_A n$ and $\dot{a} = p_A \dot{n} + n\dot{p}_A$.

Therefore, the budget constraint may be rewritten as

$$p_A \dot{n} + n\dot{p}_A = rp_A n + wL + m\Pi - PC \tag{16}$$

3. The market solution

3.1 Households

First, the representative household chooses the optimal consumption and investment plan to maximize its discounted utility, Eq. (12), subject to the budget constraint, Eq. (16). The familiar Euler equation derived from the household's intertemporal optimization is

$$\frac{\dot{C}}{C} = r - \rho - \frac{\dot{P}}{P} \tag{17}$$

Secondly, the household chooses its consumption levels for each available product variety, c_j, in order to maximize the utility of Eq. (13), given $C = Y$, $c_j = y_j$, and the budget constraint in Eq. (15). The solutions for the consumption of variety j are obtained:

$$c_j = m^{-1} (\frac{p_j}{P})^{-\sigma} C \tag{18}$$

where

$$P = \left(m^{-1} \int_0^m p_j^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}} \tag{19}$$

Eq. (18) gives the downward-sloping demand curve for goods c_j, which is faced by the final goods firms. Eq. (19) expresses the average price of the consumption goods.

Next, by combining Eq. (4) with $c = y$ and $x = l^x$, and considering the clearing condition for the final goods market in the symmetric equilibrium, we have

$$C = Y = n^{\alpha-1}L_x \tag{20}$$

Eq. (20) is the resource constraint of the economy (see Appendix B).

3.2 The final goods firms

Since the market will be symmetric in the various intermediates i, we have $x_{ij} = x_j$, $p_{ij}^x = p_j^x$, $\forall i$, in equilibrium associated with $y_j = c_j$. The final goods firms maximize the profit in Eq. (6) subject to the demand function in Eqs. (7), (8) and (18). The typical final goods firm j will charge a monopolistic markup price to the consumers as follows

$$q_j = \frac{\sigma[n^{1-\alpha}(p_j^x + \tau^x)] + \tau_y}{\sigma - 1} \tag{21}$$

3.3 Nash bargaining solution

The firm j producing final goods and firm i producing intermediate goods bargain over the franchising contract (p^x, f) simultaneously.

The division of the rent between firm j producing final goods and firm i producing intermediate goods, using Eqs. (3) and (6) and subject to Eqs. (5), (7), (8) and (21), is obtained by maximizing the following Nash product

$$\max_{p^x,f} N = (\Pi_j - \Pi_0)^{\theta}(\pi_i - \pi_0)^{1-\theta} \tag{22}$$

where Π_0 is the profit of firm j which is constant when the bargaining breaks down, namely, the minimum profit of the final goods firm, and π_0 is the profit of firm i which is constant when the bargaining breaks down, namely, the minimum profit of the intermediate goods firm. Both final goods and intermediate goods firms are bound to perform their duties in the contractible activities, but they are free to choose how much they produce in the noncontractible activities. That is to say, if the bargaining breaks down, the final goods and intermediate goods firms will mark up their prices by marginal cost, respectively.[5] θ describes the bargaining power of firm j and lies in the interval $(0,1)$. With $\theta \to 0$, the model indicates that the intermediate goods firm i has full bargaining power to decide the intermediate goods price completely. To keep the analysis simple, we assume an identical bargaining power for all final goods firms with decentralized status. The same is true for all of the intermediate goods firms.

The decentralized bargaining means that all bargains take place simultaneously

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[5] See Appendix A.

and the bargaining partners take all other intermediate goods prices and franchise fees as given.

According to the Nash bargaining solutions that are derived by maximizing Eq. (22), firm j and firm i select an optimal franchise fee and intermediate price as follows

$$p^x = w \tag{23}$$

$$f = \theta \frac{\pi_0}{m} + \frac{(1-\theta)}{n}\left[\frac{1}{\sigma-1}((w+\tau^x)+\tau_y n^{\alpha-1})\right]m^{-1}n^{1-\alpha}Y - (1-\theta)\frac{\Pi_0}{n} \tag{24}$$

Eqs. (23) and (24) describe the optimal bargaining contract in a vertically connected imperfectly competitive market structure. As in Wang et al. (2010), Eq. (23) is the pricing rule for intermediate goods, resulting from competition between the final goods firm and the intermediate goods firm, with both firms simultaneously engaging in optimization. The bargaining contract in our model is unlike the traditional franchise contract, in which the final goods firm does not have any bargaining power to determine the contract's content. The prices of the intermediate goods are equal to marginal cost, which is unrelated to the bargaining power. This is a Nash efficient result. Because the aggregate rent/franchise fee is maximized by setting the prices of the intermediate goods equal to their marginal cost, this result is interpreted as stemming from the negotiations between the intermediate goods firm and the final goods firm or the competition between the intermediate goods and the final goods firms. They obtain the maximum aggregate rent at first and then extract the extra rent, respectively, according to their bargaining power through the franchise fee. This result, which characterizes the interaction of firms in this market structure, reflects the economic consequence that double marginalization does not occur. This is a vertical integration outcome through franchise contract bargaining. Unlike in traditional models, in this paper the prices of intermediate goods are determined by negotiation, and the intermediate goods firms charge a price based on marginal cost and not on markup to the final goods firms, and then extract the profit through the franchise fee (Eq. (24)). Since vertical integration takes place, there is a perfectly elastic demand function for the intermediate goods market, and the demand function is not negatively sloped anymore.[6] Inside the square brackets on the right-hand side of Eq. (24) is the corporate income of firm j per unit of final good. The optimal franchise fee depends on the bargaining power θ. Firm i will extract all the rent if firm j has no bargaining power ($\theta \to 0$). The model gets back to the traditional R&D-driven growth model, in which the final goods firms have no bargaining power. Similarly, the rent will vanish if firm i has no bargaining power ($\theta \to 1$). This result whereby the

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[6] The standard presentation in the R&D-driven growth literature is the negative slope demand function in the intermediate goods market.

final goods firms have full bargaining power to extract the rent is quite different from that for the traditional R&D-driven growth model.

By substituting Eqs. (21) and (23) into the aggregate consumption price index, respectively, Eq. (19) can be rewritten as

$$P = \frac{\sigma}{\sigma - 1}((w + \tau^x) + \tau_y n^{\alpha - 1})n^{1-\alpha} \tag{25}$$

Then, by substituting the results, namely, Eqs. (18)-(19), (21) and (23)-(25) associated with Eqs. (7)-(8), into Eqs. (6) and (3), the profits can be expressed as

$$\Pi = \left[\theta Y - (\theta - \frac{(1-\theta)\sigma}{\sigma - 1})Y_0 \right] \frac{1}{m} \frac{1}{\sigma - 1}((w + \tau^x) + \tau_y n^{\alpha - 1})n^{1-\alpha} \tag{26}$$

$$\pi = \left[(1-\theta)Y + (\theta - \frac{(1-\theta)\sigma}{\sigma - 1})Y_0 \right] \frac{1}{n} \frac{1}{\sigma - 1}((w + \tau^x) + \tau_y n^{\alpha - 1})n^{1-\alpha} \tag{27}$$

where the subscript 0 denotes the value of the bargaining breakdown.[7]

3.4 R&D

Due to the property of perfect competition in the R&D sector ($\pi_A = 0$), we can substituting the production function, Eq. (1), into Eq. (2) and the blueprint cost or value is as follows

$$p_A = \frac{v(1-s)w}{n} \tag{28}$$

Eq. (28) indicates that the value of the blueprint is equal to its cost. The result is different from the standard free entry condition as presented in the canonical Romer model. Also it is shown that the subsidy policy implemented by the government will decrease the cost of the innovation. Furthermore, the government R&D spending will also decrease the cost of the innovation. On the other hand, the private-firms' investment that is engaged in R&D will increase the value of the innovation.

As long as the R&D cost secures the net present value of the profit in intermediate goods, that is

$$p_A = \int_t^\infty \pi(\omega) e^{-\bar{r}(t,\omega)\cdot(\omega - t)} d\omega \tag{29}$$

then it is free entry into the business of being an inventor. $\bar{r}(t,\omega) \equiv [1/(\omega - t)] \cdot \int_t^\omega r(\upsilon)d\upsilon$ in Eq. (29) represents is the average interest rate between t and ω. By differentiating the free entry condition, Eq. (29), with respect

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[7] Since we would like to analyze the macro-economy, we assume that the numbers of firms in the intermediate goods and final goods markets are the same for the economics of the bargaining and the breakdown in negotiations, $m_0 = m$, $n_0 = n$. Furthermore, the R&D activities take place in the first period of the game structure, that is, the government's expenditure on R&D activities takes place first. We then assume that $\tau_0^x = \tau^x$, $\tau_{y0} = \tau_y$.

to time, we obtain

$$r = \frac{\pi}{p_A} + \frac{\dot{p}_A}{p_A} \tag{30}$$

Eq. (30) shows a non-arbitrage condition and states that the rate of return on bonds, r, equals the rate of return on investing in R&D which includes the profit rate, π/p_A, plus the rate of capital gain or loss, $\dot{p}_A/p_A$.

3.5 The government

The government's budget constraint may be rewritten as

$$m\tau_y n^{\alpha-1} nx + m\tau^x nx = (1 - v(1-s))wL_R \tag{31}$$

where

$$m\tau_y n^{\alpha-1} nx = g(1 - v(1-s))wL_A \tag{32}$$

$$m\tau^x nx = (1-g)(1 - v(1-s))wL_A \tag{33}$$

3.6 Labor market equilibrium

To determine the aggregate dynamics of this economy, we have to find the equilibrium for the labor market and the final goods market. The labor market equilibrium condition states that total labor demand is equal to total labor supply, i.e., the optimal allocation of the given supply of labor (L) to the three sectors, $L_x + L_G + L_R = L$, and that labor is perfectly mobile across the intermediate goods sector and the blueprint industry. Since the quantity of labor allocated to the intermediate goods sector is $L_x = mnl^x$ and that allocated to the R&D industry is $L_A = \dot{n}/n$, the labor market equilibrium condition will be rewritten as

$$L_x + \frac{\dot{n}}{n} = L \tag{34}$$

4. Dynamics

Eqs. (17), (20), (25)-(28) and (30)-(34) fully define the dynamics of the economy. Since we would like to analyze the government policies and activities with regard to R&D, we assume that a vector of tax rates (τ_y, τ^x) is endogenous. Using Eq. (20) and the labor market equilibrium condition ($L_A = L - L_x$), Eqs. (32) and (33) may be rewritten as

$$\tau_y = \frac{g(1 - v(1-s))w(L - L_x)}{n^{\alpha-1}L_x} \tag{35}$$

$$\tau^x = \frac{(1-g)(1-v(1-s))w(L-L_x)}{L_x} \tag{36}$$

Substituting Eqs. (35) and (36) into Eq. (25), we obtain

$$P = \frac{\sigma}{\sigma-1} \frac{L_x + (1-v(1-s))(L-L_x)}{L_x} n^{1-\alpha} w \tag{37}$$

By multiplying Eq. (37) by $v(1-s)/n$, we obtain

$$p_A = \frac{v(1-s)}{n} \frac{\sigma-1}{\sigma} \frac{L_x n^{\alpha-1}}{L_x + (1-v(1-s))(L-L_x)} P \tag{38}$$

Differentiating Eq. (38) with respect to time

$$\frac{\dot{p}_A}{p_A} = (\alpha-2)\frac{\dot{n}}{n} + \frac{\dot{L}_x}{L_x} + \frac{\dot{P}}{P} - \frac{v(1-s)\dot{L}_x}{L_x + (1-v(1-s))(L-L_x)} \tag{39}$$

Substituting Eqs. (20), (25) and (35)-(36) into Eq. (27) and dividing by Eq. (28), we obtain

$$\frac{\pi}{p_A} = \frac{1}{(\sigma-1)v(1-s)}\left[(1-\theta)L_x + (\theta - \frac{(1-\theta)\sigma}{\sigma-1})L_{x0}\right]\frac{L_x + (1-v(1-s))(L-L_x)}{L_x} \tag{40}$$

where L_{x0}, which is constant, is the quantity of labor employed in the intermediate goods market in a successively imperfectly competitive economy.[8]

Substituting Eqs. (30), (39) and (40) into Eq. (17), we obtain

$$\begin{aligned}
\frac{\dot{C}}{C} &= \frac{1-\theta}{\sigma-1}L_x + \frac{(1-\theta)(1-v(1-s))}{(\sigma-1)v(1-s)}L + \frac{1}{\sigma-1}(\theta - \frac{(1-\theta)\sigma}{\sigma-1})L_{x0} \\
&+ \frac{1-v(1-s)}{(\sigma-1)v(1-s)}(\theta - \frac{(1-\theta)\sigma}{\sigma-1})L_{x0}\frac{L}{L_x} + (\alpha-2)\frac{\dot{n}}{n} + \frac{\dot{L}_x}{L_x} \\
&- \frac{v(1-s)\dot{L}_x}{(1-v(1-s))L + v(1-s)L_x} - \rho
\end{aligned} \tag{41}$$

Differentiating Eq. (20) with respect to time

$$\frac{\dot{C}}{C} = (\alpha-1)\frac{\dot{n}}{n} + \frac{\dot{L}_x}{L_x} \tag{42}$$

Proposition 1. *There are necessary and sufficient conditions that lead the economy to indeterminacy. There will be a high share of labor hired in intermediate goods production and a low share of labor hired in intermediate goods production in the economy. (i) If the final goods firm has no bargaining power $\theta \to 0$, then there exists a unique but unstable equilibrium. (ii) If the final goods firm's bargaining power is greater than that of the intermediate goods firm multiplied by the markup $\theta > (1-\theta)\sigma/(\sigma-1)$, then there exist two equilibria, one being unstable and determinate and the other stable and indeterminate.*

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[8] See Appendix A.

Proof. From Eqs. (41), (42) and (34), we find the dynamic equation for L_x

$$\frac{(\sigma-1)L_x v(1-s)\dot{L}_x}{(1-v(1-s))L+v(1-s)L_x}$$

$$=(\sigma-\theta)L_x^2 + \left[\frac{(1-\theta)-(\sigma-\theta)v(1-s)}{v(1-s)}L+(\theta-\frac{(1-\theta)\sigma}{\sigma-1})L_{x0}-(\sigma-1)\rho\right]L_x$$

$$+\frac{1-v(1-s)}{v(1-s)}(\theta-\frac{(1-\theta)\sigma}{\sigma-1})L_{x0}L \qquad (43)$$

Assume that $\Omega=\left[\frac{(1-\theta)-(\sigma-\theta)v(1-s)}{v(1-s)}L+(\theta-\frac{(1-\theta)\sigma}{\sigma-1})L_{x0}-(\sigma-1)\rho\right]$, and

$\Gamma=\frac{1-v(1-s)}{v(1-s)}(\theta-\frac{(1-\theta)\sigma}{\sigma-1})L_{x0}L$.

In the steady state $\dot{L}_x=0$, we obtain

$$\tilde{L}_x=\frac{-\Omega\pm\sqrt{\Omega^2-4(\sigma-\theta)\Gamma}}{2(\sigma-\theta)} \qquad (44)$$

Eq. (44) indicates that the economy exhibits an indeterminate solution if $\Omega<0$, $\Gamma>0$. The necessary and sufficient conditions are as follows

$$\frac{(1-\theta)-(\sigma-\theta)v(1-s)}{v(1-s)}L+(\theta-\frac{(1-\theta)\sigma}{\sigma-1})L_{x0}-(\sigma-1)\rho<0 \qquad (45)$$

$$\frac{1-v(1-s)}{v(1-s)}(\theta-\frac{(1-\theta)\sigma}{\sigma-1})L_{x0}L>0 \qquad (46)$$

If the final goods firm has no bargaining power, i.e., $\theta\to0$, Eq. (46) is always negative ($\Gamma<0$), thus eliminating the indeterminacy, and there exists a unique but unstable equilibrium. We also can say that this result is a traditional R&D-driven growth model in which the final goods firms have no bargaining power and the economy exhibits determinacy. On the other hand, we show that if the final goods firm's bargaining power is greater than the intermediate goods firm's bargaining power multiplied by the markup $\theta>(1-\theta)\sigma/(\sigma-1)$, then there exist two equilibria, one being unstable and determinate and the other stable and indeterminate. The economic implication of such a condition is as follows. If the bargaining power of the final goods firms is large enough, the final goods firms will extract more aggregate rent, which will cause the rent of the intermediate goods firms to fall, and hence the labor in the intermediate goods market will move to the final goods market. Therefore, the economy is likely to be characterized by indeterminacy, with a smaller share of the labor being hired in intermediate goods production, and a larger share of the labor being hired in final goods production. In addition, when the firm's R&D activities v are large or the R&D subsidy policy s is small, the indeterminacy is likely to occur.

A large firm's R&D activities will increase the value of the intermediate goods firms, and will result in a higher share of labor being hired in intermediate goods production. A small R&D subsidy policy will increase the cost of the intermediate goods firms, the intermediate goods firms will engage in fewer R&D activities that will result in a smaller share of labor being hired in intermediate goods production. Furthermore, when the elasticity of substitution σ is large, Eqs. (45) and (46) are easy to satisfy, and then multiple equilibria emerge. For example, if the final goods market is characterized by too much perfect competition, then the economy will be characterized by indeterminacy.

According to Eq. (43), the first-order and second-order conditions are as follows

$$\frac{\partial \dot{L}_x}{\partial L_x} = 2(\sigma - \theta)L_x + \Omega \underset{<}{\overset{>}{}} 0 \qquad (47)$$

$$\frac{\partial^2 \dot{L}_x}{\partial L_x^{\,2}} = 2(\sigma - \theta) > 0 \qquad (48)$$

Eqs. (47) and (48) imply that there are two equilibria for $\tilde{L}_x$ in the steady state. One

is stable, namely, the low share of labor hired in intermediate goods production ($\breve{L}_x$),

and the other is unstable, namely, the high share of labor hired in intermediate goods
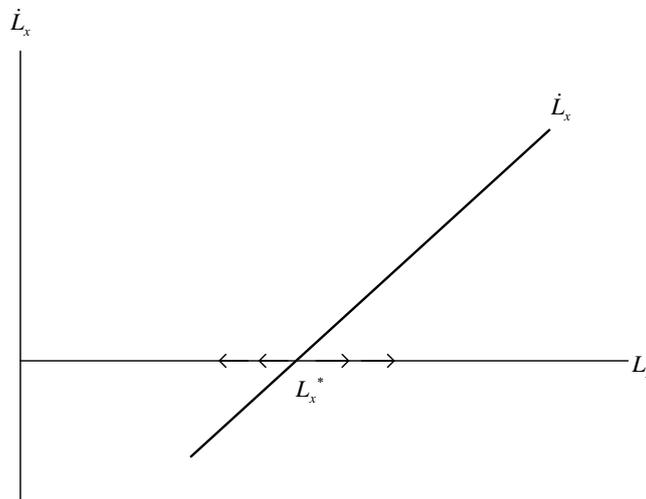
production ($\hat{L}_x$).

Figure 1. A unique and determinate equilibrium; $\theta \to 0$ (traditional R&D-driven growth model)

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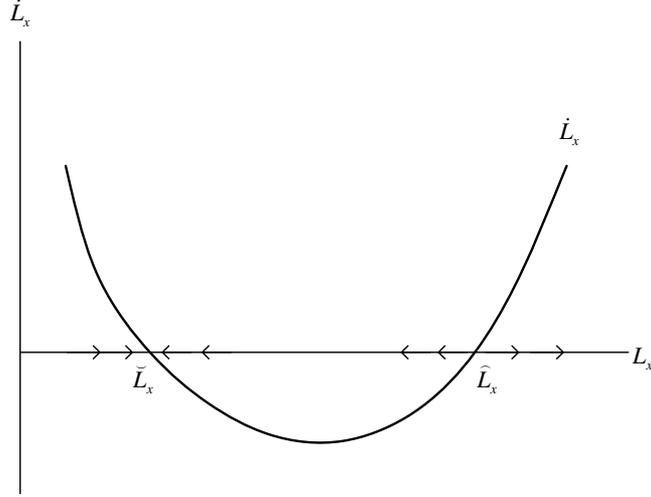
Figure 2. Two indeterminate equilibria; $\theta > (1-\theta)\dfrac{\sigma}{\sigma-1}$

Figures 1 and 2 provide a graphical illustration of Proposition 1. Figure 1 depicts case (i) where there is only one unstable and hence globally determinate steady-state equilibrium, while Figure 2 presents the case where there are two steady-state equilibria. Point $\breve{L}_x$ represents a locally stable and indeterminate equilibrium. Point $\widehat{L}_x$, on the other hand, is a locally unstable and hence determinate equilibrium.

5. Steady states

In the generalized case, we show that there can be two long-run equilibria, and both of them can be locally determinate or indeterminate. Thus, we cannot exclude any of them on the grounds of stability. That is to say, the conditions, Eqs. (45) and (46), are satisfied. In the steady state $\dot{L}_x = 0$, and by totally differentiating Eq. (43), the results of the comparative static state are as follows

$$\frac{\partial \widetilde{L}_x}{\partial \theta} = \frac{1}{2(\sigma-\theta)\widetilde{L}_x + \Omega} \times (\widetilde{L}_x + \frac{1-v(1-s)}{v(1-s)}L) \times \left[\widetilde{L}_x - (1+\frac{\sigma}{\sigma-1})L_{x0} \right]^{>}_{<} 0 \qquad (49)$$

$$\frac{\partial \widetilde{L}_x}{\partial s} = \frac{-1}{2(\sigma-\theta)\widetilde{L}_x + \Omega} \times \frac{(1-\theta)L}{v(1-s)^2} \times$$

$$\left[\widetilde{L}_x - (\frac{\theta}{1-\theta} - \frac{\sigma}{\sigma-1})\frac{1}{\sigma}\widetilde{L}_x - (\frac{\theta}{1-\theta} - \frac{\sigma}{\sigma-1})\left(\frac{1-v(1-s)}{v(1-s)\sigma}L - L_{x0}\right) \right]^{>}_{<} 0 \qquad (50)$$

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$$\frac{\partial \tilde{L}_x}{\partial v} = \frac{1}{2(\sigma - \theta)\tilde{L}_x + \Omega} \times \frac{(1-\theta)L}{v^2(1-s)} \times$$

$$\left[\tilde{L}_x - (\frac{\theta}{1-\theta} - \frac{\sigma}{\sigma-1})\frac{1}{\sigma}\tilde{L}_x - (\frac{\theta}{1-\theta} - \frac{\sigma}{\sigma-1})\left(\frac{1-v(1-s)}{v(1-s)\sigma}L - L_{x0}\right) \right] \substack{> \\ <} 0 \qquad (51)$$

The signs of Eqs. (49)-(51) depend on the sign of ($2(\sigma - \theta)\tilde{L}_x + \Omega$) in Eq. (47).[9]

From Eq. (34), in the steady state the growth rates of innovation depend on the state of $\tilde{L}_x$ such that

$$\breve{\gamma}_n = L - \hat{L}_x \qquad (52)$$

otherwise

$$\hat{\gamma}_n = L - \breve{L}_x \qquad (53)$$

where $\gamma_n = \dot{n}/n$. Eq. (52) denotes the low balanced equilibrium growth rate of innovation and Eq. (53) the high balanced equilibrium growth rate of innovation. Hence, the effects of the government's R&D policies and bargaining power on the balanced equilibrium growth rate depend on Eqs. (49)-(51), that is, on the sign of ($2(\sigma - \theta)\tilde{L}_x + \Omega$) in Eq. (47).

Proposition 2. *The effects of the government direct expenditure on R&D activities and subsidies to defray the R&D costs of firms on the economy lead to entirely different results depending on whether there is a high balanced growth path or a low balanced growth path. In addition, the bargaining power between the firms producing intermediate goods and final goods also has reverse effects on the multiple equilibria for the economy.*

Proof. From Eq. (44), we have

$$\tilde{L}_x = \begin{cases} \breve{L}_x, & \text{if } 2(\sigma - \theta)\tilde{L}_x + \Omega < 0 \\ \hat{L}_x, & \text{if } 2(\sigma - \theta)\tilde{L}_x + \Omega > 0 \end{cases} \qquad (54)$$

When the economy is characterized by a low share of labor hired in intermediate

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[9] The third term on the right-hand side in Eq. (49) is positive, since the equilibrium is characterized by subgame perfection. Furthermore, we assume that the third term on the right-hand side in Eqs. (50) and (51) is positive for the analysis of the R&D policies' effects.

goods production, $\breve{L}_x$, the denominator of the first fraction on the right-hand side of Eqs. (49)-(51), is negative, i.e., $2(\sigma - \theta)\tilde{L}_x + \Omega < 0$. On the other hand, when the economy is characterized by a high share of labor hired in intermediate goods production, $\hat{L}_x$, the denominator of the first fraction on the right-hand side of Eqs. (49-(51) is positive, i.e., $2(\sigma - \theta)\tilde{L}_x + \Omega > 0$. Hence, the effects of the exogenous parameters are entirely reversed between the high balanced growth path economy and the low balanced growth path economy.

Differentiating Eq. (52) with respect to θ, s, and v, and associated with Eqs. (49)-(51), we obtain

$$\text{sign}(\frac{\partial \breve{\gamma}_n}{\partial \theta}) = -\text{sign}(\frac{\partial \hat{L}_x}{\partial \theta}) = \text{sign}(2(\sigma - \theta)\tilde{L}_x + \Omega) \tag{55}$$

$$\text{sign}(\frac{\partial \breve{\gamma}_n}{\partial s}) = -\text{sign}(\frac{\partial \hat{L}_x}{\partial s}) = -\text{sign}(2(\sigma - \theta)\tilde{L}_x + \Omega) \tag{56}$$

$$\text{sign}(\frac{\partial \breve{\gamma}_n}{\partial v}) = -\text{sign}(\frac{\partial \hat{L}_x}{\partial v}) = \text{sign}(2(\sigma - \theta)\tilde{L}_x + \Omega) \tag{57}$$

Differentiating Eq. (53) with respect to θ, s, and v, and associated with Eqs. (49)-(51), we obtain

$$\text{sign}(\frac{\partial \hat{\gamma}_n}{\partial \theta}) = -\text{sign}(\frac{\partial \breve{L}_x}{\partial \theta}) = -\text{sign}(2(\sigma - \theta)\tilde{L}_x + \Omega) \tag{58}$$

$$\text{sign}(\frac{\partial \hat{\gamma}_n}{\partial s}) = -\text{sign}(\frac{\partial \breve{L}_x}{\partial s}) = \text{sign}(2(\sigma - \theta)\tilde{L}_x + \Omega) \tag{59}$$

$$\text{sign}(\frac{\partial \hat{\gamma}_n}{\partial v}) = -\text{sign}(\frac{\partial \breve{L}_x}{\partial v}) = -\text{sign}(2(\sigma - \theta)\tilde{L}_x + \Omega) \tag{60}$$

6. The effects of R&D policies on economic growth

6.1 High balanced growth path economy

When the economy is characterized by a low share of labor hired in intermediate goods production, $\breve{L}_x$, the denominator of the first fraction on the right-hand side of Eqs. (49)-(51) is negative, i.e., $2(\sigma - \theta)\tilde{L}_x + \Omega < 0$. At this time, the economy has a high balanced growth path ($\hat{\gamma}_n$). Therefore, the effects of the parameters on the economic growth are as follows

$$\frac{\partial \widehat{\gamma}_n}{\partial \theta} = -\frac{\partial \breve{L}_x}{\partial \theta} > 0 \tag{61}$$

$$\frac{\partial \widehat{\gamma}_n}{\partial s} = -\frac{\partial \breve{L}_x}{\partial s} < 0 \tag{62}$$

$$\frac{\partial \widehat{\gamma}_n}{\partial v} = -\frac{\partial \breve{L}_x}{\partial v} > 0 \tag{63}$$

Eq. (61) illustrates that increasing the bargaining power of final goods firms will increase the high balanced growth rate of innovation. An increase in the bargaining power of a final goods firm will result in more profits. This will decrease the profits of the intermediate firm. Since it pertains to the way the bargaining process impacts the way in which the expected profits of an innovation are being computed, the intermediate firm will thus employ less labor. Then, labor will be transferred to the R&D sector, which stimulates economic growth. That is to say, the final goods firm plays an important role in a high balanced growth path economy in boosting the rate of economic growth. In addition, Eq. (62) indicates that the government's policy of subsidizing the R&D cost of the firms has a negative effect on the high balanced growth rate. In other words, the government raises the rate of the subsidy, which will cause the growth rate to slow down. This is because the subsidy policy will increase the profit of the intermediate goods firm, and hence the intermediate goods firm will hire more labor for production, thus decreasing the amount of labor engaged in R&D. The fewer the R&D activities there are, the less the economy will grow. Moreover, if the government directly increases the expenditure on the R&D activities, it will reduce the growth rate, too (Eq. (63)). Therefore, the government's expenditure on R&D will crowd out the private R&D activities.[10] This result supports real data compiled by OECD (1989) that indicates that the share of government research has fallen since the mid-1970s. At the same periods, the United States has low output growth in early 1970s, but there is a high output growth in later 1970s (page 271, Blanchard, 2011).

6.2 Low balanced growth path economy
When the economy is characterized by a high share of labor hired in intermediate goods production, $\widehat{L}_x$, the denominator of the first fraction on the right-hand side of

Eqs. (49)-(51) is positive, $2(\sigma - \theta)\tilde{L}_x + \Omega > 0$. At this time, the economy is on a low

balanced growth path ($\breve{\gamma}_n$). Therefore, the effects of the parameters on the economic

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[10] About 75% of the roughly 1 million U.S. scientists and researchers working in R&D are employed by firms. U.S. firms' R&D spending accounts for more than 20% of their spending on gross investment and more than 60% of their spending on net investment (page 255, Blanchard, 2011).

growth are as follows

$$\frac{\partial \breve{\gamma}_n}{\partial \theta} = -\frac{\partial \widehat{L}_x}{\partial \theta} < 0 \tag{64}$$

$$\frac{\partial \breve{\gamma}_n}{\partial s} = -\frac{\partial \widehat{L}_x}{\partial s} > 0 \tag{65}$$

$$\frac{\partial \breve{\gamma}_n}{\partial v} = -\frac{\partial \widehat{L}_x}{\partial v} < 0 \tag{66}$$

Eq. (64) illustrates that an increase in the bargaining power of intermediate goods firms will increase the low balanced growth rate of innovation. That is to say, the intermediate goods firms play an important role in a low balanced growth path economy in enhancing the rate of economic growth. When the intermediate goods firms extract more franchise fees from the final goods market, there are more profits provided to R&D activities, and thus there is more labor to engage in R&D the more the economy grows. In addition, Eq. (65) indicates that the effect of a government's subsidy policy on the R&D cost of the firms in a low balanced growth path economy is positive. In other words, a government that raises the ratio of the subsidy to the R&D cost of the firms will cause the growth rate to increase. Since the subsidy policy will encourage labor to engage in R&D and reduces the labor hired in the intermediate goods market, the economy will grow. Moreover, if the government directly increases its expenditure on R&D activities, it will increase the growth rate, too (Eq. (66)).[11] This result is the same as that in OECD (1989), which indicates that the share of research performed by the government varies across countries and is generally higher among smaller R&D nations (that is, among nations with smaller R&D to GDP ratios). Examples of such countries include Iceland, Greece, Ireland, and Portugal. The intuition for this result is that the more labor that the government hires to engage in R&D, the more labor in the intermediate goods market that will be transferred to the R&D sector. Hence, the government plays an important role in enhancing the rate of economic growth, and the policies on R&D activities are helpful in a low balanced growth path economy.

7. Conclusion

By analyzing the implications of R&D policies in an R&D endogenous growth model with a bargaining game structure in a vertically-connected imperfectly competitive market, we have shown that the bargaining power may give rise to multiple growth paths with global indeterminacy. With regard to the implications for R&D policies,

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[11] Starting in 1960, four countries, namely, Taiwan, South Korea, Singapore and Hong Kong, a group of countries sometimes referred to as the 'Four Tigers', started to quickly catch up with the developed countries. In 1960, their average output per person was about 16% of the U.S. level; by 2004, it had increased to 65% of the U.S. level (see Table 10-3, Blanchard, 2011).

the government not only subsidizes the R&D costs of the firms, but also engages in R&D activities. We have demonstrated how R&D policies can serve as a potential tool which can improve the growth performance of the economy in multiple equilibria.

We find that the economy is characterized by two balanced equilibrium growth rates, which comprise a high balanced growth equilibrium and a low balanced growth equilibrium. In a high growth rate economy, the government's subsidy policy and the R&D activities will crowd out the private R&D activities, and hence the R&D policies are of no help to the economic growth. In other words, the final goods firms play an important role in driving the economic growth, and the stronger the bargaining power that the final goods firms have, the more the economy grows. On the contrary, in a low growth path economy the government that directly engages in R&D activities plays an important role in economic growth. The R&D policies of the government have a positive effect on the economic growth. The intermediate goods firms play an important role in driving the economic growth, and the stronger the bargaining power that the intermediate goods firms have, the more the economy grows.

This paper finds entirely different effects on a high growth rate economy and on a low growth rate economy. The government and the firms that manufacture intermediate goods and final goods play different roles in the process of economic growth.

Appendix A

There were two types of firms – intermediate goods firm and final goods firm in a successively imperfect competitive economy. They achieve their maximizing profits respectively described as follows.

Firm j in the final goods market optimizes its production plan and face the maximizing profit problem as

$$\max_{x_{ij0}} \Pi_{j0} = q_{j0} y_{j0} - \int_0^{n_{t0}} (p_{ij0}^x + \tau_0^x) x_{ij0} di \qquad (A1)$$

subject to Eqs. (4), (7), (18) and $y_{j0} = c_{j0}$. (Note: Subscript 0 denotes the case of traditionally pricing, corresponding to negotiation breakdown. That means, the intermediate goods firm and the final goods firm do not integrate interactively.)

In the symmetric equilibrium, $x_{ij0} = x_{j0}$, $p_{ij0}^x = p_{j0}^x$, $\forall i$, the first-order condition is given by

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$$x_{j0} = [(p_{j0}^x + \tau_0^x)n_0^{1-\alpha} + \tau_{y0}]^{-\sigma}(\frac{\sigma}{\sigma-1})^{-\sigma}m_0^{-1}n_0^{-\alpha}(P_0)^{\sigma}C_0 \tag{A2}$$

Eq. (A2) states the demand for intermediate goods market.

While firm i in the intermediate goods market chooses the price to maximize its profit

$$\max_{p_{i0}^x} \pi_{i0} = m_0 p_{i0}^x x_{i0} - m_0 w l_{i0}^x \tag{A3}$$

subject to its production function ($x_{i0} = l_{i0}^x$) and demand shown in Eq. (A2).

The first-order condition is thus given by

$$p_0^x = \frac{\sigma w + \tau_{y0}n_0^{\alpha-1} + \tau_0^x}{\sigma-1} \tag{A4}$$

Eq. (A4) indicates that firm i of intermediate goods charges the markup price which is above the marginal cost to firm j of final goods. This result is similar to the solution in the traditional R&D growth model.

Substituting Eq. (A4) into (A2) and using Eq. (4) and (18), we obtain the equilibrium demand for intermediate goods market. Then the price of the final goods is derived by

$$p_{j0} = \frac{\sigma}{\sigma-1}\left[\frac{\sigma(w+\tau_0^x)n_0^{1-\alpha} + \tau_{y0}}{\sigma-1} + \tau_{y0}\right] \tag{A5}$$

Eqs. (A5) and (A4) state that double marginalization could take place due to successive markups. Namely, both firms in the intermediate goods market and the final goods market set the markup price while facing their consumers.

Following Eq. (A5), we obtain the average price of the consumption goods (P_0), and profits (Π_0, π_0) of the intermediate goods firm and the final goods firm respectively in a successive monopolistic competitive economy. The results are shown as follows.

$$P_0 = \frac{\sigma}{\sigma-1}\left[\frac{\sigma(w+\tau_0^x)n_0^{1-\alpha} + \tau_{y0}}{\sigma-1} + \tau_{y0}\right] \tag{A6}$$

$$\Pi_0 = \frac{\sigma}{(\sigma-1)^2}\frac{1}{m_0}((w+\tau_0^x)n_0^{1-\alpha} + \tau_{y0})Y_0 \tag{A7}$$

$$\pi_0 = \frac{1}{\sigma-1}\frac{1}{n_0}((w+\tau_0^x)n_0^{1-\alpha} + \tau_{y0})Y_0 \tag{A8}$$

The dynamics system of the non-integrated economy can be expressed as:

$$(\frac{\dot{C}}{C})_0 = \frac{(1-v(1-s))L + v(1-s)L_{x0}}{v(1-s)(\sigma-1)} + (\alpha-2)(\frac{\dot{n}}{n})_0 + \frac{\dot{L}_{x0}}{L_{x0}}$$

$$-\frac{(1-(vs+(1-v)))\dot{L}_{x0}}{L_{x0}+(vs+(1-v))(L-L_{x0})}-\rho \tag{A9}$$

$$(\frac{\dot{n}}{n})_0 = L - L_{x0} \tag{A10}$$

$$(\frac{\dot{C}}{C})_0 = (\alpha-1)(\frac{\dot{n}}{n})_0 + \frac{\dot{L}_{x0}}{L_{x0}} \tag{A11}$$

Combining Equations (A9)-(A11), we find the dynamic equation for L_{x0}

$$\frac{(1-(vs+(1-v)))\dot{L}_{x0}}{L_{x0}+(vs+(1-v))(L-L_{x0})} = \frac{1-v(1-s)\sigma}{v(1-s)(\sigma-1)}L + \frac{\sigma}{\sigma-1}L_{x0} - \rho \tag{A12}$$

Since the coefficient $\sigma/(\sigma-1)$ of L_{x0} is positive, we have $\dot{L}_{x0}=0$. Its steady state

value is

$$L_{x0} = \frac{v(1-s)\sigma-1}{v(1-s)\sigma}L + \frac{\sigma-1}{\sigma}\rho \tag{A13}$$

Appendix B

The household's budget constraint is shown by

$$p_A\dot{n} + n\dot{p}_A = rp_An + wL + m\Pi - PC \tag{B1}$$

Substituting the zero profit condition: $p_A\dot{n} = v(1-s)wL_A$, labor market equilibrium:

$L_x + L_A = L$, and non-arbitrage condition: $r = \frac{\pi}{p_A} + \frac{\dot{p}_A}{p_A}$ into Eq. (B1), we can get

$$v(1-s)wL_A + n\dot{p}_A = (\frac{\pi}{p_A} + \frac{\dot{p}_A}{p_A})p_An + w(L_x + L_A) + m\Pi - PC \tag{B2}$$

Rewrite Eq. (B2) into

$$v(1-s)wL_A = n\pi + w(L_x + L_A) + m\Pi - PC \tag{B3}$$

and substitute π and Π, namely, Eqs. (26) and (27), into Eq. (B3), then obtain

$$v(1-s)wL_A = Y\frac{1}{\sigma-1}((w+\tau^x)+\tau_y n^{\alpha-1})n^{1-\alpha} + w(L_x + L_A) - PC \tag{B4}$$

Since the taxes are endogenous, substituting the government budget constraint

$\tau_y = \frac{g(1-v(1-s))wL_A}{n^{\alpha-1}L_x}$, and $\tau^x = \frac{(1-g)(1-v(1-s))wL_A}{L_x}$ into Eq. (B4), we obtain

$$v(1-s)wL_A = Y\frac{1}{\sigma-1}\frac{L_x + (1-v(1-s))L_A}{L_x}wn^{1-\alpha} + w(L_x + L_A) - PC \tag{B5}$$

Owing to $Y = n^{\alpha-1}L_x$, (B5) can be transferred as

$$v(1-s)wL_A = \frac{1}{\sigma-1}(n^{1-\alpha}Y + (1-v(1-s))L_A)w + w(n^{1-\alpha}Y + L_A) - PC \tag{B6}$$

Rearrange Eq. (B6) as

$$v(1-s)wL_A = \frac{\sigma}{\sigma-1}n^{1-\alpha}wY + \frac{1}{\sigma-1}(1-v(1-s))wL_A + wL_A - PC \qquad (B7)$$

Substituting $\quad P = \dfrac{\sigma}{\sigma-1}\dfrac{L_x + (1-v(1-s))wL_A}{L_x}n^{1-\alpha}w\quad$ into (B7), we obtain

$$0 = \frac{\sigma}{\sigma-1}n^{1-\alpha}wY - \frac{\sigma}{\sigma-1}n^{1-\alpha}wC \qquad (B8)$$

Finally, we derive the resource constraint as follows

$$Y = C \qquad (B9)$$

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