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Endogenous fluctuations with procyclical R&D

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ABSTRACT

The literature on endogenous growth cycles predicts the countercyclical allocation of resources to R&D. However, this prediction is not supported by empirical studies. This study considers the R&D-based growth model with endogenous fluctuations introducing population growth and a negative externality that affects the productivity of R&D. We show that this simple modification makes R&D investment procyclical along sustained business cycles using both an overlapping generation framework and an infinitely-lived agent framework.

1. Introduction

This study examines how R&D activity varies over the business cycle using the framework of the R&D-based growth models. Studies of the interaction between R&D and endogenous fluctuations were pioneered by Judd (1985) and Deneckere and Judd (1992). By applying a bifurcation theorem, they found fluctuating equilibrium paths in the variety-expansion model without capital accumulation. However, in the above mentioned models, a sustained R&D effort did not contribute to long-run growth because it was canceled out by the obsolescence and dilution of knowledge. Matsuyama (1999, 2001) has modified the model in Deneckere and Judd (1992) by introducing capital accumulation and Romer's (1990) idea of endogenous growth,[1] and investigated endogenous fluctuations with sustained long-run growth.[2] One of the main predictions of these theoretical models was the countercyclical behavior of R&D over sustained growth cycles; that is, with low growth, resource allocation to R&D is high. In addition, this countercyclicality of R&D made productivity improvements countercyclical.[3]

Francois and Lloyd-Ellis (2003) have studied the endogenous growth model with endogenous fluctuations, which was based on the quality-ladder framework of Grossman and Helpman (1991) and the theory of the implementation cycles of Shleifer (1986). In their model, productivity improvements were procyclical; however R&D expenditures were still countercyclical. Other studies, including Wälde (2002), Bental and Peled (1996), and Francois and Lloyd-Ellis (2008), predicted the countercyclical behavior of R&D.[4]

The prediction that R&D expenditures are countercyclical is difficult to justify from empirical studies. Wälde and Woitek (2004) have studied the cyclical properties of R&D in G7 countries using annual data from 1973 to 2000. They found that aggregate R&D expenditures tended to be procyclical and argued that the prediction of Matsuyama (1999, 2001) was counterfactual. Fatás (2000) and Comin and Gertler (2006) also have found a highly procyclical tendency of R&D expenditures using U.S. data. In particular, Comin and Gertler (2006) focused on longer-term oscillations than conventional business cycles. They termed these oscillations the "medium-term cycle" that includes frequencies between 6 months and 50 years. In this respect, there is a close relationship between their empirical study and our theoretical analysis. Geroski and Walters (1995) argued that their analysis of the U.K. data revealed that productivity improvements were also procyclical. Barlevy (2007), using data from both the National Science Foundation (NSF) and Standard & Poor's Compustat database of publicly traded

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[1] In Matsuyama (2001), capital accumulation is derived from intertemporal optimization of the infinitely lived agents. Matsuyama (1999) did not present intertemporal optimization explicitly.

[2] More precise studies of the dynamics of Matsuyama's model were presented by Mitra (2001), Mukherji (2005), Gardini et al. (2008), and Yano et al. (2011).

[3] In business cycles, when any economic quantity is positively correlated with the business condition of the economy, it is said to be procyclical. Countercyclical is the opposite of procyclical. In this study, the growth rate of real GDP is used as a procyclical economic indicator.

[4] Francois and Lloyd-Ellis (2008) did not interpret the activity that was a source of productivity improvements as R&D, but as an "entrepreneurial search." However, its process was formally identical to the R&D process in the earlier models of Grossman and Helpman (1991) and Francois and Lloyd-Ellis (2003).

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companies, found a positive correlation between the growth rate of R&D at the industry level as well as the aggregate level.

The main purpose of this paper is to include the procyclical behavior of R&D into the endogenous fluctuation model. We modify the variety-expansion model in Matsuyama (1999, 2001), introducing population growth and a negative externality that affects the productivity of R&D. We assume that finding new knowledge becomes more difficult as economies become technologically more advanced, as in the semi-endogenous growth model in Jones (1995) and Segerstrom (1998).[5] This assumption has been first proposed to eliminate the scale effect, which is a serious counterfactual prediction in the first-generation R&D-based endogenous growth models, such that an economy with a large population grows faster.[6]

Relevant related literature includes Wälde (2005), Francois and Lloyd-Ellis (2009), Comin and Gertler (2006), and Barlevy (2007). Francois and Lloyd-Ellis (2009) have studied the endogenous business cycle model based on their previous work (Francois and Lloyd-Ellis, 2003). They decomposed the innovation process into three distinct stages: R&D, commercialization, and innovation. Their model illustrated the procyclical movement of R&D, and they determined that the countercyclical movement of commercialization played a central role in this new result. Furthermore, they showed that the total expenditure for innovation, defined as the sum of expenditures for R&D and commercialization, moved procyclically. Wälde (2005) also illustrated procyclical R&D behavior by using a quality-ladder framework with capital accumulation. The Francois and Lloyd-Ellis (2009) and Wälde (2005) models are similar to ours in that they assumed a negative externality of knowledge accumulation and derive non-scale growth with endogenous fluctuations. On the other hand, Comin and Gertler (2006) and Barlevy (2007) have discussed the cyclicality of R&D over the business cycles that were caused by exogenous shocks. The former was based on a variety-expansion framework and used similar approach to Francois and Lloyd-Ellis (2009), i.e., decomposing the innovation process.[7] The latter, using a quality-ladder framework, showed that the equilibrium R&D was procyclical in a decentralized market. However, optimal R&D was found to be countercyclical by a central planner's problem.[8]

As the aforementioned studies illustrate, the theoretical explanation of the procyclicality of R&D is one of the most controversial topics in the studies of R&D and business cycles. This study achieves the procyclical R&D behavior under an assumption that is simpler than those of Francois and Lloyd-Ellis (2009) and Wälde (2005). In addition, it does not require exogenous shocks, unlike the Comin and Gertler (2006) and Barlevy (2007) models.

The rest of this paper is organized as follows. Section 2 sets up the model used in our theoretical investigation and derives the law of motion that characterizes the equilibrium path of the economy. Section 3 examines the dynamic properties of the model and illustrates that the equilibrium path fluctuates endogenously. Section 4 focuses on period 2 cycles and studies the cyclicality of R&D investment. Section 5 provides conclusions.

2. The model

Our model considers the dynamic model based on Matsuyama (1999). Time is discrete and indexed by $t = 0, 1, 2, \ldots$. There is a single final good taken as a numeraire that is produced using intermediate goods and labor. It can be consumed or invested. A new variety of intermediate goods is invented by allocating capital for R&D activities. Inventors enjoy a one-period monopoly by patent protection. The available intermediate goods are produced by multiple intermediate firms using capital. Finally, we assume two-period-lived overlapping generation (OLG) households, who inelastically supply labor when young.

2.1. Final goods

We assume that perfect competition prevails in the final goods market. The production function is given by

$$Y_t = AL_t^{1-\alpha}\int_0^{N_t} x_t(z)^{\alpha}dz, \quad 0<\alpha<1, \quad A>0, \tag{2.1}$$

where Y_t is the final output, L_t is the inelastically supplied labor, $x_t(z)$ is the amount of the intermediate good indexed by z, and $1/(1-\alpha)$ denotes the elasticity of substitution between all pairs of intermediate goods. N_t is the number of available intermediate goods in period t that represents the technology level of the economy.

Profit maximization yields $w_t = (1-\alpha)Y_t/L_t$ and the inverse demand function for each intermediate good $z \in (0, N_t]$ as $p_t(z) = \alpha AL_t^{1-\alpha}x_t(z)^{-(1-\alpha)}$, where w_t is the real wage rate and $p_t(z)$ is the price of the intermediate good z.

2.2. Intermediate goods

Each intermediate good is produced by using one unit of capital. Let r_t denote the price of capital. Because of limited patent protection, the "old" intermediate goods, $[0, N_{t-1})$, are supplied competitively. Hence, the price is equal to the marginal cost, $p_t(z) = r_t$, for $z \in (0, N_{t-1}]$. However, the "new" intermediate goods invented in period $t-1$, $(N_{t-1}, N_t]$, are supplied monopolistically and sold at the monopoly price, $p_t(z) = r_t/\alpha$, for $z \in (N_{t-1}, N_t]$. All intermediate goods enter symmetrically into the production of the final good, i.e., $x_t(z) = x_{ct}$ for $z \in [0, N_{t-1}]$ and $x_t(z) = x_{mt}$ for $z \in (N_{t-1}, N_t]$. We can easily illustrate that $x_{mt} = \alpha^{\frac{1}{1-\alpha}}x_{ct}$ holds and the maximized monopoly profits are $\Pi_t(z) = \Pi_t \equiv \frac{1-\alpha}{\alpha}x_{mt}r_t$ for $z \in (N_{t-1}, N_t]$.

2.3. R&D

The number of intermediate goods N expands according to the following equation:[9]

$$N_t - N_{t-1} = \eta\frac{R_t}{N_{t-1}^{\phi}}, \quad N_0 > 0, \quad \phi > 0, \quad \eta > 0,$$

where R_t is the amount of the capital allocated to R&D. Following the formation adopted in Jones (1995), we assume that the past discoveries make inventing a new machine more difficult. This external effect is captured by ϕ.

Each inventor enjoys a one-period monopoly and earns profits Π_t. Therefore, in equilibrium, the following free-entry condition must be satisfied:

$$\Pi_t \le \eta^{-1}N_{t-1}^{\phi}r_t, \quad \text{with an equality whenever } N_t > N_{t-1}.$$

The break-even point of x_{mt} is given by $\bar{x}_{mt} \equiv \frac{\alpha}{1-\alpha}\eta^{-1}N_{t-1}^{\phi}$. It becomes larger for a large value of ϕ, since R&D becomes costlier for any given N_{t-1} and L_t.

Finally, clearing the capital market requires $K_t = R_t + (N_t - N_{t-1})x_{mt} + N_{t-1}x_{ct}$, where K_t is the amount of capital accumulated in period $t-1$ and available in period t. The available capital is utilized by R&D, producing monopolistic intermediate goods, and producing competitive intermediate goods.

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[5] Jones (1995) called such an externality the fishing-out effect.

[6] Jones (1995) was also the study based on the variety-expansion model in Romer (1990). However, its balanced growth path (BGP) has a saddle property and no endogenous fluctuation occurs as proven by Arnold (2006). Note that in order to examine the dynamics analytically, Arnold (2006) assumed constant returns to labor in R&D, which was not assumed in Jones' original model.

[7] They introduced the stage of "adoption" instead of commercialization.

[8] For other recent work on R&D procyclicality, see Nuño (2011).

[9] This specification is based on Rivera-Batiz and Romer's (1991) "lab equipment model."