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A Monetary Variety-Expanding Growth Model with a Cash-in-Advance Constraint on Manufacturing

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Abstract

We highlight one difference in predictions between Romer's expanding variety model and the Schumpeterian quality-ladder model, when there exists a cash-in-advance (CIA) constraint on manufacturing. In the expanding variety model, a higher nominal interest rate decreases growth, and a negative nominal interest rate would be socially optimal. In contrast, in the quality-ladder model, a higher nominal interest rate increases growth. In the quality-ladder model, when the step-size of innovation is small (i.e., there may be R&D over-investment when the business-stealing effect dominates), the optimal nominal interest rate would be negative. When the step-size of innovation is large, the optimal nominal interest rate would be positive.

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1 Introduction

On June 5, 2014, the European Central Bank (ECB) unprecedentedly became the first major central bank to take one of its main interest rates below zero – the interest rate on the deposit facility was to be decreased by 10 basis points to -0.10% effective 11 June, 2014. Can such a policy be socially optimal? In this study, we analyze the effects of nominal interest rates on economic growth and welfare in both Romer's expanding variety model and a Schumpeterian quality-ladder model, when there is a cash-in-advance (CIA) constraint on manufacturing. Our study is important for the following two reasons.

First, in real world situations, manufacturing is often subject to liquidity requirements. The importance of the CIA constraint on manufacturing has been highlighted by Stockman (1981) and Abel (1985). Fuerst (1992) and Liu et al. (2008) have provided empirical support for the importance of the CIA constraint on manufacturing. As illustrated in new growth models (hereafter NGMs) (Romer, 1990; Aghion and Howitt, 1992), the monopolistic profit from producing intermediate goods is the source of long-run growth. When manufacturing is subject to cash requirements, the cost of manufacturing/production and thereby the monopolistic profit for entrepreneurs would inevitably be affected. As a result, the growth rate and social welfare would also be affected. Therefore, it is important for us to consider the CIA constraint on manufacturing in NGMs.

Second, we find that the theoretical predictions from these two types of models – Romer's expanding variety model v.s. the Schumpeterian quality-ladder model – differ substantially, which has strong implications for how monetary policy is conducted. Our theoretical findings are presented as follows.

In the expanding variety model, higher nominal interest rates cause growth to decrease. The reason is as follows. With a CIA constraint on manufacturing, a positive nominal interest rate acts as a tax on manufacturing/production, which decreases the monopolistic profit from innovations, which in turn decreases the return to households in financing innovations and thereby growth. Concerning welfare, because there is always R&D underinvestment, a negative nominal interest rate would be socially optimal. In contrast, in the quality-ladder model, a higher nominal interest rate increases growth because it shifts labor away from manufacturing/production to R&D. As more labor is devoted to R&D, growth would be higher in the quality-ladder model. Concerning welfare, the nominal interest rate that maximizes social welfare depends on the step-size of innovation. When the step-size of innovation is small (i.e., there may be R&D over-investment when the business-stealing effect dominates), the optimal nominal interest rate would be negative. A negative nominal interest acts as a subsidy on manufacturing/production, which hires labor away from R&D and thereby increases welfare. When the step-size of innovation is large, the optimal nominal interest rate would be positive.

It is worth highlighting that the difference in the growth effects of inflation is not due to variety expansion versus quality improvement per se; rather, the difference is due to the lab-equipment innovation process (i.e., R&D uses final goods) in this version of the variety-expanding model versus the knowledge-driven innovation process (i.e., R&D uses labor) in the quality-ladder model (see discussions in Chu, Pan and Sun, 2012). The intuition can be explained as follows. With the lab-equipment innovation process in the Romer model, the growth rate depends on the monopolistic profit, which is decreasing in the nominal interest rate via the CIA constraint on manufacturing. With the knowledge-driven innovation process in the Schumpeterian model, the growth rate depends on R&D

labor, which is increasing in the nominal interest rate via a reallocation of labor from manufacturing to R&D.

Therefore, the conduct of monetary policy should take the results into consideration. In other words, in the presence of a CIA constraint on manufacturing, the negative nominal interest rate adopted by ECB may be defendable by the expanding variety model, but it is hard to support by the quality-ladder model.

Our study complements the recent literature of monetary NGMs – models that introduce money into Romer (1990) or Aghion and Howitt (1992). The recent contributions include Marquis and Reffett (1994); Chu, Lai and Liao (2012); Chu and Lai (2013); Chu and Cozzi (2014); Chu and Ji (2014); and Chu et al. (2014). Marquis and Reffett (1994) and Chu, Lai and Liao (2012) consider a monetary variety-expanding growth model with a CIA constraint on consumption and show that the Friedman rule is optimal, but they do not consider the CIA constraint on manufacturing. Chu and Lai (2013), Chu and Cozzi (2014), Chu and Ji (2014) and Chu et al. (2014) consider a monetary quality-ladder growth model instead of a variety-expanding model, and only Chu and Cozzi (2014) analyze the CIA constraint on manufacturing along with other CIA constraints. This manuscript contributes to the literature by showing that the growth effect of monetary policy via the CIA constraint on manufacturing can be drastically different under different innovation processes.

2 A Monetary Expanding Variety Model

Our model is based on Romer's (1990) expanding variety model presented in Barro and Sala-i-Martin (2004, ch. 6). The economy consists of a final goods sector, an intermediate goods sector, households, and a monetary authority. Each intermediate good represents an innovation. Each innovation is a project that is conducted by an entrepreneur. The innovation cost (the cost of R&D) of each intermediate good is a fixed amount, η. Each intermediate good is owned by a monopolistic entrepreneur. There is free-entry in R&D.

2.1 The Households

At time t, the population size of each household is fixed at L. There is a unit continuum of identical households, which have a lifetime utility function as

$$U = \int_0^\infty e^{-\rho t} \ln(c_t)\, dt, \tag{1}$$

where c_t is per capita real consumption at time t; $\rho > 0$ is the rate of time preference. The results that we are emphasizing do not depend on elastic labor supply. Therefore, for simplicity, we focus on fixed labor supply. Each individual is endowed with one unit of labor. Therefore, L is also equal to the aggregate labor supply.

Each household maximizes its lifetime utility given in equation (1) subject to the asset-accumulation equation given by

$$\dot{a}_t + \dot{m}_t = r_t a_t + w_t + \Gamma_t - c_t - \pi_t m_t + i_t b_t, \tag{2}$$

where a_t is the real value of equity shares in monopolistic intermediate goods firms owned by each member of households; r_t and w_t are the rate of real interest and wage, respectively; m_t is the real money balance held by each person, and π_t is the cost of holding money; Γ_t is the lump-sum transfer of the seigniorage revenue from the monetary authority (or a lump-sum tax if $\Gamma_t < 0$). The CIA constraint is given by $b_t \leq m_t$, where b_t is the amount of money borrowed from each member of households by entrepreneurs to finance manufacturing, and its return is i_t.

The no-arbitrage condition is $i_t = \pi_t + r_t$, where i_t is also the nominal interest rate. Using Hamiltonian, the optimality condition for consumption is

$$\frac{1}{c_t} = \mu_t, \tag{3}$$

where μ_t the Hamiltonian co-state variable on (2).

The Euler equation is

$$-\frac{\dot{\mu}_t}{\mu_t} = r_t - \rho. \tag{4}$$

2.2 The final goods sector

The final goods sector is competitive. The production function of a final good firm i is

$$y_i = \sum_{j=1}^{N} X_{ij}^{\alpha} L_i^{1-\alpha}, \tag{5}$$

where N is the number of innovations, X_{ij} is the amount of intermediate good j used by final good firm i, and L_i is the labor input of final good firm i.

The final goods firms maximize their profit by taking as given the wage rate w_t, and the prices of intermediate goods P_j. The aggregate demand for the j-th intermediate good is obtained from the first-order condition (FOC) associated with X_{ij}:

$$X_j = \sum\nolimits_i X_{ij} = L \left(\frac{\alpha}{P_j} \right)^{\frac{1}{1-\alpha}}. \tag{6}$$

The optimal condition for labor demand yields

$$w_t = \frac{(1-\alpha) Y}{L}, \tag{7}$$

where $Y = \sum_i y_i$ is the total amount of final output.

2.3 The intermediate goods sector

Intermediate goods are inputs of the final goods sector. Intermediate goods firms transform one unit of final good into one unit of an intermediate good. As discussed in the introduction, in this version of the monetary Romer model, R&D uses final goods as the factor input (i.e., the lab-equipment R&D process).

We have normalized final goods' price to unity. The intermediate goods firms have to borrow cash from households to finance their purchasing of final good, subject to the nominal interest rate i_t. Therefore, with the CIA constraint on manufacturing, the marginal/unit cost for the intermediate good firm (i.e., the manufacturing firm) would be $(1+i_t)$.

As in the standard Romer expanding variety model, when an entrepreneur obtains a patent on one intermediate good (one variety) he would be the monopoly supplier. Therefore, the j-th intermediate good firm's problem becomes

$$\max_{P_j} \Pi_j = [P_j - (1+i)] X_j = [P_j - (1+i)] L \left(\frac{\alpha}{P_j}\right)^{\frac{1}{1-\alpha}}, \tag{8}$$

where the last equality uses (6). Therefore, the intermediate good firm's optimal price is $P_j = \frac{1+i}{\alpha}$, and the monopoly profit is

$$\Pi_j = \left(\frac{1}{\alpha} - 1\right)(1+i)\left(\frac{\alpha^2}{1+i}\right)^{\frac{1}{1-\alpha}} L. \tag{9}$$

2.4 Research arbitrage

We denote $v_t(j)$ as the value of the monopolistic firm specializing in selling intermediate good j. The asset equation for v_t is

$$r_t v_t = \Pi_j. \tag{10}$$

Free-entry into R&D yields zero expected profit for entrepreneurs:

$$v = \eta. \tag{11}$$

2.5 The general equilibrium

The general equilibrium is a time path of prices $\{P_j,\, r_t,\, w_t,\, i_t\}$ and allocations $\{c_t,\, m_t,\, y_t,\, X_j\}$, which satisfy the following conditions at each instance of time:

- households maximize utility taking prices $\{r_t,\, w_t,\, i_t\}$ as given;
- competitive final-goods firms maximize profit taking $\{w_t,\, P_j\}$ as given;
- monopolistic intermediate-goods firms choose $\{P_j\}$ to maximize profit;
- free entry into R&D;
- final goods market clears (i.e., $Y_t = c_t L + \eta \dot{N} + \sum_j X_j$);

- the value of monopolistic firms adds up to the value of households' assets (i.e., $vN = \eta N = a_t L$); the amount of money borrowed by manufacturing is $X_j = b_t L$.

We focus on the balanced growth path along which allocation variables such as c_t, m_t, Y_t, and N all grow at a constant rate. Using (3), (4), (10), and (11), the growth rate, g, is

$$g = \frac{\Pi_j}{\eta} - \rho. \tag{12}$$

2.6 Optimal monetary policy

Substituting out Π_j using (9) in (12), the decentralized economy's growth rate g^d is

$$g^d = \frac{\left(\frac{1}{\alpha} - 1\right)(1+i)\left(\frac{\alpha^2}{1+i}\right)^{\frac{1}{1-\alpha}} L}{\eta} - \rho, \tag{13}$$

Proposition 1 *The balanced growth rate is a decreasing function of nominal interest rate with a CIA constraint on manufacturing.*

Proof: Given the balanced growth rate in (13), differentiating g^d with respect to i yields

$$sign\left(\frac{\partial g^d}{\partial i}\right) = sign\left\{-\frac{\alpha}{1-\alpha}(1+i)^{-\frac{1}{1-\alpha}}\right\} < 0. \tag{14}$$

Q.E.D.

The mechanism can be seen from (9). Under the CIA constraint on manufacturing, the monopolistic profit from innovations given in (9) negatively depends on the nominal interest rate. When manufacturing firms need to borrow money from households to finance their purchase of inputs, they have to pay households the nominal interest rate. The borrowing cost resulting from the CIA constraint on manufacturing reduces the monopolistic profit from innovation. A lower return from financing innovations would decrease households' willingness to save to finance R&D, which ends up lowering growth.

Proposition 2 *With a CIA constraint on manufacturing, there is a unique, negative nominal interest rate* $i^* = \left(\alpha^{1/\alpha} - 1\right) < 0$ *that maximizes social welfare.*

Proof. The social planner maximizes the utility of the representative household given in (1). The resource constraint for the social planner is

$$Y = L^{1-\alpha} N^{1-\alpha} X^{\alpha} = C + X + \eta \dot{N}, \tag{15}$$

where X is the amount of final good used in the production of intermediate goods.

Using Hamiltonian, the socially optimal growth rate, denoted g^s, is given by

$$g^s = \frac{\left(\frac{1-\alpha}{\alpha}\right)\alpha^{\frac{1}{1-\alpha}} L}{\eta} - \rho. \tag{16}$$

Now comparing (13) and (16), we have

$$g^d > g^s \text{ iff } i < \left(\alpha^{1/\alpha} - 1\right) < 0. \quad (17)$$

Q.E.D. Therefore, with the CIA constraint on manufacturing, the Friedman rule (Friedman, 1969) is optimal given the zero lower bound on the nominal interest rate.

There is always under-investment in R&D (and welfare loss) due to monopolistic pricing in Romer's expanding variety model. Therefore, it is optimal to subsidize R&D, which is achieved by a negative nominal interest rate. With a CIA constraint on manufacturing, a negative nominal interest is a subsidy to entrepreneurs when they borrow money to buy final goods to produce intermediate goods. As a result, the monopolistic profit from innovations will increase, as will the growth rate. This would increase welfare as long as the nominal interest rate is still above the cut-off value $\left(\alpha^{1/\alpha} - 1\right)$.

However, when the nominal interest rate falls below $\left(\alpha^{1/\alpha} - 1\right)$, decentralized growth still increases, but social welfare decreases. This is because there may be too much R&D. A negative nominal interest rate acts as a subsidy to entrepreneurs, but the cost is borne by households. Households' welfare from future higher growth comes at the cost of foregone current consumption. When the nominal interest rate is too low, the welfare loss from foregone current consumption may dominate the welfare gain from higher future growth.

It is true that some banks have charged negative interest rates in reality, but households can respond by withdrawing their money from their bank accounts and refusing to lend money to firms, thus avoiding negative interest charges. Therefore, in a sustainable equilibrium, we should respect the zero lower bound on the nominal interest rate. In other words, with the CIA constraint on manufacturing, the Friedman rule (Friedman, 1969) is optimal given the zero lower bound on the nominal interest rate.

3 Comparing with the Monetary Quality-Ladder Model

Here we contrast our results with that use the monetary quality-ladder model following Chu and Cozzi. It would be sufficient for us to discuss how the aforementioned results differ from the ones in Chu and Cozzi without repeating their model and derivations.

First, with the monetary quality-ladder model, the effect of the nominal interest rate on growth predicted by the expanding variety model (see Proposition 1) is opposite to that in the quality-ladder model. With a CIA constraint on manufacturing, a positive nominal interest acts as a tax on entrepreneurs when they borrow money from households for manufacturing (i.e., producing intermediate goods). In the expanding variety model, the increased manufacturing cost decreases the monopolistic profit from innovations. This in turn decreases growth because the return to households' investment (the ratio of the monopolistic profit from innovation to the fixed R&D cost) decreases. In contrast, in the quality-ladder model, there is a labor reallocation effect. When manufacturing firms' cost of hiring labor increases, their labor demand drops. Therefore, more labor would be absorbed into R&D. In quality-ladder models, the growth rate positively and linearly depends on the share of labor employed in R&D. Therefore, a higher interest rate promotes growth in the quality-ladder model. The introduction has presented the underlying reason for the difference in the growth effects of inflation in the two types of monetary new growth models.

Second, concerning social optimum in the monetary quality-ladder model, the laissez-faire growth in quality-ladder models could be excessive due to excessive research (R&D overinvestment) when the business-stealing effect dominates. The size of the business-stealing effect depends on γ (the step-size of innovation). A lower value of γ increases the business-stealing effect, which may result in too much research in a decentralized economy. Therefore, in this case, the optimal interest rate would be negative. As discussed, a negative nominal interest rate acts as a subsidy to manufacturing firms, which increases the labor demand of these firms, thus decreasing the amount of labor used in R&D. This is welfare-improving when there is R&D overinvestment. Similarly, a larger value of γ may result in too little research in a decentralized economy. Therefore, in this case, the optimal interest rate would be positive. As discussed, a positive nominal interest rate acts as a tax on manufacturing firms, which decreases the labor demand of these firms, thus increasing the amount of labor used in R&D. This is welfare-improving when there is R&D underinvestment.

Therefore, the Friedman rule could be suboptimal when there is R&D underinvestment. This prediction differs from Chu and Cozzi who highlight the CIA constraint on R&D investment. Nevertheless, the underlying mechanism is the same. What differs is the optimal tools/channels to achieve the socially optimal outcome. Due to the labor re-allocation between manufacturing and R&D investment in the quality-ladder model, the optimality of the Friedman rule depends on the form of the CIA constraint. In other words, the optimality of the Friedman rule (i.e., the conduct of monetary policy) depends on whether the CIA constraint applies to manufacturing or R&D investment.

4 Conclusions

We contribute to the literature on the nexus between monetary policy and growth/welfare by incorporating a CIA constraint on manufacturing in both Romer's expanding variety model and the Schumpeterian quality-ladder model. We find that the effects of the nominal interest rate on growth and welfare differ substantially between these two types of models. In the expanding variety model, a higher nominal interest rate decreases growth because it decreases the monopolistic profit from innovations, which in turn decreases the return to households in financing innovations and thereby growth. Concerning welfare, because there is always R&D underinvestment in the expanding variety model, a negative nominal interest rate would be socially optimal. In contrast, in the quality-ladder model, a higher nominal interest rate increases growth because it shifts labor away from manufacturing/production to R&D. As more labor is devoted to R&D, growth would be higher in the quality-ladder model. Concerning welfare, because there may be R&D over-investment in the quality-ladder model, the nominal interest rate that maximizes social welfare depends on the step-size of innovation. When the step-size of innovation is small (i.e., there may be R&D over-investment), the optimal nominal interest rate would be negative. A negative nominal interest acts as a subsidy on manufacturing/production, which hires away labor from R&D and thereby increases welfare. When the step-size of innovation is large (i.e., there may be R&D under-investment), the optimal nominal interest rate would be positive. A positive nominal interest acts as a tax on manufacturing/production, which reallocates labor into R&D and thereby increases welfare.

As presented in the introduction, the difference in the growth effects of inflation in the two types of monetary new growth models is not due to variety expansion versus quality improvement per se; the difference is due to the lab-equipment innovation process (i.e., R&D uses final goods) in this version of the variety-expanding model versus the knowledge-driven innovation process (i.e., R&D uses labor) in the quality-ladder model. With the lab-equipment innovation process in the Romer model, the growth rate depends on the monopolistic profit, which is decreasing in the nominal interest rate via the CIA constraint on manufacturing. With the knowledge-driven innovation process in the Schumpeterian model, the growth rate depends on R&D labor, which is increasing in the nominal interest rate via a reallocation of labor from manufacturing to R&D. This is the message that we would like to confer in this paper. The policy implication is that optimal monetary policy should take the results into consideration.

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