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Abstract

This paper explores the macro effects of monetary policy in a Schumpeterian growth model with an endogenous market structure and distinct cash-in-advance (CIA) constraints on consumption, production, and two distinct types of R&D investment – in-house R&D and entry investment. We show that the CIA constraints work through various channels and the effects of monetary policy depend on the strength of each channel. Although inflation seems like a uniform tax imposed on the whole economy, an identical monetary policy can render different distortions of inflation on the economy and give rise to quite different consequences. Specifically, if in-house R&D or quality improvement-type R&D (entry investment or variety expansion-type R&D) is subject to the CIA constraint, raising the nominal interest rate decreases (increases) the firm’s market size and economic growth. If either production or consumption is subject to the CIA constraint, growth is immune from money, while the market structure and employment are responsive. Besides, in the presence of various cash constraints our model also generates rich transitional dynamics in response to a change in monetary policy.

JEL classification: O30, O40, E41.
Keywords: CIA constraints on R&D, endogenous market structure, monetary policy, growth.

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1 Introduction

This paper explores the long-run steady-state and short-run transition effects of monetary policy in a Schumpeterian growth model by considering various CIA constraints on consumption, production, and two types of R&D investment, namely, in-house R&D and entry investment. Our analytical framework is a monetary variant of the "second generation" endogenous growth model with an "endogenous market structure" developed by Peretto (1998a). This is the first time a second-generation growth model has been used to study the macro consequences of monetary policy by shedding light on the importance of distinct cash constraints on R&D investments.\(^1\) The endogeneity of the market structure provides new insights to the monetary literature. Meanwhile, this "monetary implication" complements the studies of Peretto (2003 and 2007), who restricts the focus to the effects of fiscal instruments.

In the model, the market structure (measured by the endogenously-determined number of firms and firm market size) shapes the profit-seeking firm's behavior by affecting the returns to innovation and entry. To characterize both market structure and innovation simultaneously, we consider both horizontal (variety expansion) and vertical (quality improvement) dimensions of technology space.\(^2\) In the vertical dimension, incumbents reduce their production cost by conducting in-house R&D. In the horizontal dimension, new entrants compete with incumbents by bringing a new product into the market. The quality-improved R&D interacts with the variety-expanded entry and this interaction is affected by the government's interest rate policy through various cash constraints (on in-house R&D, entry, production and consumption). Accordingly, we show that CIA constraints work through various channels and the effects of monetary policy depend on the strength of each channel. Money can be either supernormal (being independent of growth, but possibly having a transitory effect) or non-supernormal (having a permanent growth effect) in the presence of a variety of CIA constraints. Although inflation seems like a uniform tax imposed on the whole economy, because of the distinct CIA constraints, an identical monetary policy can render different distortions of inflation on the economy and give rise to quite different macro consequences.

Our model is built to be consistent with three major sets of facts. First, the empirical evidence (e.g., Hall 1992 and Himmelberg and Petersen 1994) reports a strong R&D-cash flow sensitivity for firms. The main reason which has been pointed out by Hall and Lerner (2010, p. 612) is that more than 50 percent of R&D spending is the wages and salaries of highly

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\(^1\)While Chu and Ji (2012) also use a second-generation growth model to examine the growth effect of monetary policy, their analysis is confined to a Lucasian (2000) CIA economy without any cash constraint on R&D. Chu and Cozzi (2013) analyze a CIA constraint on R&D, but their analysis is based on a quality-ladder R&D model with a fixed market structure, which cannot discuss the case where the CIA constraint is subject to entry.

\(^2\)As stressed by Peretto and Connolly (2007) and Ji (2012), the traditional growth model with only one dimension of innovation is not able to model both innovation and market structure.
skilled technology scientists and engineers; their efforts form the firm’s knowledge base, from which profits are generated. Because the knowledge asset can dramatically disappear when such workers leave or are laid off and because R&D projects often take a long time, R&D-intensive firms are required to hold cash in order to smooth their R&D spending over time. Brown and Petersen (2009) offer direct evidence that US firms relied heavily on cash reserves to smooth R&D spending during the 1998-2002 boom. In particular, cash holdings have a stronger impact on R&D in younger firms, which are more likely to face binding liquidity and financing constraints (see Brown and Petersen 2009, 2011 and Brown et al. 2012).

Relative to the traditional physical investment, R&D activities also exhibit a stronger investment-cash flow sensitivity. Given that the conventional monetary model only focuses on the CIA constraint on consumption and physical investment (e.g., Stockman 1981 and Wang and Yip 1992), the lack of an appropriate consideration of a CIA constraint on R&D investments may fail to not only reflect reality, but also to provide a complete picture for the implications of monetary policy. To fill the gap, we set up a more generalized model in which all consumption, production, quality-improved R&D and variety-expanded R&D could be subject to the CIA constraint.

Second, our model is consistent with the fact of industrial organization (IO) in the sense that R&D is conducted predominately by incumbent firms (see Dosi 1998 and NSF 2010). Bartelsman and Doms (2000) and Foster and Krizan (2000) clearly indicate that 75% of the average total factor productivity (TFP) growth at the industry level is accounted for by incumbents and only 25% of average TFP growth is accounted for by the entry of new establishments. The so-called creative destruction, in the sense that new firms with better technology replace old firms with backward technology, is responsible for only a little technical progress (see OECD 2003). By contrast, in the present model the two-dimensional R&D competition (between quality-improved incumbents and variety-expanded entrants) seems to be more appropriate to capture the reality. Importantly, such a model setting is able to endogenize the market structure, which eliminates the scale effect with the IO foundation to which we now turn.

Third, models that come out of the first wave of endogenous growth theory (in which each individual firm’s market size is exogenous and equal to the entire economy or a fixed portion of it) give rise to an inappropriate prediction – the "scale effect" (referring to a positive relationship between the economy’s size and its growth rate) that is inconsistent with the actual data (Backus et al. 1992). For example, in the first-generation Schumpeterian models, the scale effect...
effect implies that productivity growth increases in the level of R&D, which is refuted by the coexistence of an upward trend in R&D labor and no trend in TFP growth (Jones 1995).

To remove the scale effect of R&D, the previous models with a one-dimensional innovation either utilize some simple, but somewhat arbitrary, normalization or incorporate diminishing returns to the stock of knowledge in R&D (the semi-endogenous growth model), while retaining the market structure exogenously determined.\(^5\) By contrast, the second-generation model (such as the present one) posits a process of development of new product lines which can effectively fragment the aggregate market in sub-markets whose size does not increase with total R&D labor or population. By shedding light on the two-dimensional innovation (quality-improved incumbents and variety-expanded entrants), the endogeneity of the market structure allows the proliferation of product varieties to reduce the effectiveness of R&D aimed at quality improvement, by causing it to be spread more thinly over a larger number of different products. Thus, the scale effect is eliminated. The hypothesis of product proliferation not only is supported by the US data (see Laincz and Peretto 2006),\(^6\) but is also consistent with the fact that the in-house R&D activities depend on firm market size which is endogenously determined through the market structure (see Cohen and Klepper 1996 a,b and Adams and Jaffe 1996). Given the evidence, one should be cautious as the results of the long-run monetary effects are based on the Schumpeterian growth model without an endogenous market structure, such as in Funk and Kromen (2010). In effect, as we will see later, our results differ from theirs.

The main results of our study are summarized as follows. In terms of the steady-state effects, we show that if in-house R&D (resp. entry investment) is subject to the CIA constraint, raising the nominal interest rate decreases (resp. increases) the firm’s market size (i.e., the average market size per firm) and the TFP growth.\(^7\) However, if either production or consumption is subject to the CIA constraint, money is neutral to economic growth due to the scale invariance. Why could an identical monetary policy end up with such different consequences? Intuitively, a higher nominal interest rate raises the cost of holding money, thus reducing the real money balances in the economy. If the money balances are required to engage in in-house R&D and entry investment is not restricted by such a constraint, in-house R&D becomes more expensive, compared to firm entry. Thus, the return to incumbents (quality improvement-type innovators) decreases, while the return to entrants (variety expansion-type innovators) increases. As entry increases, the firm’s market size shrinks, thus leading to a lower rate of innovation and economic growth. However, if entry investment, instead of in-house R&D, is subject to the CIA constraint,

\(^5\)The semi-endogenous growth theory claims that as technology develops and becomes increasingly complex, sustained growth in R&D labor becomes necessary just to maintain a given rate of TFP growth.

\(^6\)Zachariadis (2003) and Ha and Howitt (2007) also present evidence in favor of the hypothesis of product proliferation.

\(^7\)Fisher and Seater (1993) have presented evidence to support the possibility of money non-supernelterality.
raising the nominal interest rate restricts the variety-expanded innovation. Since the resource
shifts away from entry to in-house R&D, the firm's market size increases. A larger firm's market
size motivates firms to engage in more R&D investment, and therefore the TFP growth rate
rises in response. The Schumpeterian paradigm indicates that, in favor of economic growth,
some extent of monopoly power is needed to act as the reward accruing to the successful firms
from their innovative activities. In this monetary version of the Schumpeterian model, a rise
in the interest rate renders the existing innovators with such an extent of monopoly power by
increasing entry costs and hence enhancing economic growth, if entry investment is subject
to a larger cash constraint. The case can be true, particularly when in practice some sort of
the CIA constraint is a crucial binding restriction on the creation of new businesses (Janiak
and Monteiro 2011) and younger firms are more likely to face binding liquidity and financing

The steady-state inflation effect conforms to the Fisher equation prescribe, regardless of
what kinds of activities are constrained by money balances. In the long run, increasing the
nominal interest rate requires an increase in the rate of money growth and, consequently,
a higher nominal interest rate is associated with a higher inflation rate. This inflation effect,
together with the growth effect above, give rise to novel economic implications. First, our model
identifies a new channel that characterizes a positive effect of inflation on economic growth (i.e.,
the Mundell-Tobin effect). A particular emphasis is that our result is purely via the liquidity
constraint and market-structure adjustment, rather than the conventional asset-substitution
effect, stressed by Mundell (1963) and Tobin (1965). Second, due to the variety of the CIA
constraints, our analysis predicts a mixed long-run relationship between growth and inflation,
which reconciles the recent empirical findings. While studies by Fisher (1983) and Cooley
and Hansen (1989) report a negative relationship between steady inflation and output/growth
across countries, recent works by Bullard and Keating (1995), Bruno and Easterly (1998),
and Ahmed and Rogers (2000) seemingly find no robust or even positive correlation in low-
inflation industrialized economies. The recent evidence refers to a non-monotonic relationship,
suggesting that the real output/growth effect of inflation could be either positive or negative,
depending on the status quo inflation rate.

By focusing on the case with the CIA constraint on production or consumption, we find
that due to the scale-invariant property, growth is immune to monetary policy, but employment
is negatively responsive. To compare the four distinctive CIA constraints, we find that in
response to a unified monetary policy the relationship between employment and growth is non-
monotonic. They could be either positively related (as in the case with the CIA constraint on

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8Janiak and Monteiro (2011) provide substantial evidence to show that the liquidity constraint is often a
binding constraint facing aspiring entrepreneurs.
in-house R&D or entry), negatively related (as in the case with the CIA constraint on in-house R&D), or independent (as in the case with the CIA constraint on production and consumption). This outcome differs from that of the first-generation growth model with the scale effect, which refers to an unambiguously positive employment-growth relationship. Nonetheless, it allows us to explain the empirical finding whereby there is little evidence of a robust bivariate relationship between the employment and growth rates (Bean and Pissarides 1993) and there exists an empirical possibility of a negative employment-growth relationship (Gordon 1997).

Besides, monetary policy also leads to rich transitional dynamics when the market structure is endogenized. Our transition analysis shows that in response to a higher nominal interest rate, the firm size and the TFP growth both monotonically decrease (resp. increase) to the steady-state value, if in-house R&D (resp. entry) is subject to the CIA constraint. However, in either case, along the transition path the consumption growth rate, the employment rate, and the consumption expenditure may mis-adjust from their long-run steady states. The dynamic adjustments are relatively monotonic under the case where production or consumption is restricted by the CIA constraint. Interestingly, when the cash constraints on in-house R&D, entry investment, and consumption all play a role in this story, the TFP growth rate may also exhibit a mis-adjustment in transition. Specifically, in response to a higher nominal interest rate, the TFP growth rate rises in the long run, while it falls during the transition.

In a closely-related paper, Chu and Cozzi (2013) elegantly build a two-sector, scale-invariant growth model to show that a higher interest rate has a mixed growth effect, depending on whether manufacturing production or quality-improved R&D is subject to a cash constraint.9 Our study differs from theirs in three significant respects. First, on the ground of model setting, the mechanism behind the result is quite different. In their model, R&D has only a vertical dimension, while our paper highlights the endogeneity of the market structure, which consists of both vertical and horizontal R&D. Due to the mechanism difference, our model with an endogenous market structure refers to money superneutrality of growth when manufacturing production is subject to the CIA constraint, while they obtain a positive growth effect. Furthermore, our study attempts to show that an identical monetary policy could end up with very different macro consequences due to the existence of a variety of CIA constraints. Second, the endogeneity of the market structure enables us not only to differentiate between the monetary implications for the quality-improved and variety-expanded R&D, but also to explore the effects on the market and firm sizes. It is important since the industrial distribution of firm size has been shown to be crucial to both the short-run business cycle (e.g., Bernanke et al. 1996 and Cooley and Quadrini 2006) and the long-run economic growth/welfare (e.g.,

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9They proved that this result is valid in either a scale-invariant model with a fixed market structure or a semi-endogenous growth model.
Pagano and Schivardi 2003 and Janiak and Monteiro 2011). For example, by the simplicity of an exogenous technology, Cooley and Quadrini (2006) show that the responses of small and large firms differ substantially to a monetary shock. In the absence of an R&D sector, Janiak and Monteiro (2011) emphasize the CIA constraint on new establishments and numerically show that market structure plays a crucial role in terms of enhancing the welfare cost of inflation. Our focus apparently differs from theirs. In the second-generation growth model with an endogenous technology formation, we investigate how monetary policy alters the number of firms and the firm’s market size, which in turn affect the technological accumulation and TFP growth via various CIA constraints. Third, Chu and Cozzi (2013) focus on the welfare implications with a particular emphasis on the issues concerning a zero-interest-rate policy and over(under)investment in R&D, while we focus on the growth implications with an additional analysis of the transitional effect.

2 The Model

There is a monetary variant of the Peretto (1998a) model with CIA constraints on in-house R&D, entry, production and consumption. The economy consists of households, firms (incumbents and entrants), and a government (solely represented by the monetary authority). Time $t$ is continuous. For compact notation, the time index is suppressed throughout the paper.

2.1 Households

Consider an economy with a population growth rate $\lambda$, which is associated with a population size $L$. Each household chooses consumption $C$ and leisure $(1 - l)$ (where $l$ is the normalized time and $l$ are working hours) to maximize the following discounted sum of future instantaneous utilities:

$$U(t) = \int e^{-(\rho - \lambda)t}[\ln C + \gamma \ln (1 - l)]dt,$$

subject to the budget constraint

$$\dot{A} + \dot{M}_m = (r - \lambda)A + l + iB + T - (\pi + \lambda)M_m - E,$$

and the CIA constraint

$$\xi_C E \leq M_m - B,$$
where $M_m = \frac{M_L}{P_m L}$. In line with Peretto (1998a), the price of labor is a numeraire. By defining $M_L$ as the nominal money balances, $P_m$ can then be viewed as the price of money in terms of labor and, accordingly, $M_m$ represents the real money balances per capita.\(^{10}\) Thus, all quantity (non-price) variables are real and in per capita terms: $A$ is real asset holdings, $M_m$ is real money holdings, $B$ is the real loans for R&D and production activities, $E$ is the real consumption expenditure per capita, and $T$ is the real lump-sum transfer from the government. Moreover, $r$ is the real interest rate, $i$ is the nominal interest rate, $\pi$ is the inflation rate, and $\rho$ is a constant time preference rate.

The CIA constraint (3) indicates that the real money balances $M_m$ held by the households are required not only to purchase consumption goods $E$, but also to finance the firms’ investment $B$. The amount $M_m - B$ is available for transactions for purchasing consumption goods and $\xi_C$ is the weight of consumption on the cash constraint. The term $B$ can be simply thought of as one-period loans, which are used to finance either the incumbent firms’ in-house (quality improvement-type) R&D, new firms’ entry investment (variety expansion-type R&D), or their production. As will be clear in Subsection 2.2, the amount of $B$ crucially depends on how much these R&D and production activities are restricted by the cash (liquidity) constraint. The specification of one-period loans is similar to Williamson (1987) and, accordingly, $iB$ is then the interest rate payment on the loan for R&D and production activities. In Subsection 2.4, when deriving the no-arbitrage condition between this loan and other assets (i.e., Fisher’s equation $i = r + \pi$), we can see that the loan rate $i$ is also the nominal interest rate.

Households consume all differentiated intermediate goods, and hence we set the bundle of consumption $C$ as a CES combination of $N$ types of intermediate goods. Let $c_i$ be the consumption of the intermediate good $j$ and $\epsilon$ be the elasticity of substitution. Thus, we can specify:

$$C = \left[ \int_o^N c_j^{(\epsilon-1)/\epsilon} dj \right]^{1/\epsilon}.$$  \hspace{1cm} (4)

By denoting $p_j$ as the price for intermediate good $j$ in terms of labor, the expenditure per capita then is:

$$E = \int_o^N p_j c_j dj.$$  \hspace{1cm} (5)

Define $\eta$ and $\psi$ as the multipliers associated with (2) and (3). Thus, the first-order conditions necessary for the household’s optimization problem are given by:

\(^{10}\)The choice of deflator does not alter our main results.
\[
\frac{1}{C} = P_C(\eta + \psi\xi_C),
\]
\[
\frac{\gamma}{1-l} = \eta,
\]
\[
\psi = \eta i,
\]
\[-\eta(\pi + \lambda) + \psi = -\dot{\eta} + \eta(\rho - \lambda),
\]
\[\eta(r - \lambda) = -\dot{\eta} + \eta(\rho - \lambda),
\]
where \( P_C \equiv \left[ \int_0^N p_j^{1-\epsilon} d\eta \right]^\frac{1}{1-\epsilon} \). Apparently, the first two equations are the optimal conditions for consumption and leisure, respectively, and the latter three equations are the optimal conditions for three distinct types of assets. Furthermore, a simple two-stage budgeting procedure yields the demand for the consumption good \( j \):
\[
c_j = E\left[ \frac{p_j^{-\epsilon}}{\int_0^N p_k^{1-\epsilon} d\eta} \right]
\]
As a result, the total demand for all goods is given by:
\[
X_j = Lc_j = LE\left[ \frac{p_j^{-\epsilon}}{\int_0^N p_k^{1-\epsilon} d\eta} \right]. \tag{6}
\]
Accordingly, we can have the market share of firm \( j \) as follows:
\[
\kappa_j = \frac{p_j^{1-\epsilon}}{\int_0^N p_k^{1-\epsilon} d\eta} = \frac{P_j X_j}{LE}. \tag{7}
\]
Since there is a continuum of goods and each firm is atomistic, taking \( X_j \) as given, monopolistic competition then prevails and individual firms face isoelastic demand curves.

### 2.2 Firms

The interaction between incumbents and entrants is the core of the model. There are two dimensions of technology change in this sector – production cost reduction (the vertical dimension) and variety expansion (the horizontal dimension). In the vertical dimension, incumbents engage in in-house R\&D in order to reduce the production costs and earn higher profits.\(^{11}\) In the horizontal dimension, entrepreneurs make entry decisions and compete with incumbents for market share. Through firm entry, the number of firms \( N \) and the individual firm market

\(^{11}\)Cost reducing technological progress is equivalent to quality improvement progress. See Tirole (1988).
share $\kappa_j$ are endogenously determined.\textsuperscript{12} In this section, we first focus on the determination of the price and investment in R&D of incumbents given the existing market structure and then turn to the endogeneity of the market structure, which is related to the entry decisions of entrepreneurs.

### 2.2.1 Incumbents

The goods sector comprises a continuum of monopolistically competitive incumbents, each of which produces a single intermediate good $X_j$ with the following technology:

$$L_{X_j} = h(Z_j) X_j,$$

(8)

where $h(Z_j) = Z_j^{-\theta}$, with $0 < \theta < 1$. Each incumbent $j$ undertakes R&D to increase the knowledge $Z_j$. An increase in knowledge decreases the cost of production $L_{X_j}$. Thus, (8) can be rewritten as $X_j = Z_j^\theta L_{X_j}$, which indicates that an increase in knowledge improves the productivity of production labor. The firms accumulate knowledge according to:

$$\dot{Z}_j = \alpha K L_{Z_j},$$

(9)

The flow of knowledge $\dot{Z}_j$ depends on R&D productivity $\alpha$, the employment in the R&D sector of firm $j$, $L_{Z_j}$, and the stock of public knowledge:

$$K \equiv \int_0^N \kappa_j Z_j dj,$$

where $\kappa_j$ is defined in (7). Note that the knowledge is non-rival within a firm and augments labor at the firm level and firm size (firm employment $L_{Z_j}$ and $L_{X_j}$) is endogenously determined by firm entry. These give rise to the main difference between our model and the previous growth models without market structure, which presume that knowledge augments all labor in the economy. Such a presumption is not consistent with the IO findings. The reader can refer to Peretto (1999), Dosi (1988), Nelson and Winter (1992), and Malerba (1992) for the relevant discussions.

\textsuperscript{12}In line with the common specification in the literature on macroeconomics and growth, we assume that each firm produces only one product. This rules out the possibility whereby an incumbent firm simultaneously engages in quality-improved and variety-expanded R&D. Nonetheless, if a firm can produce multiple products, it would not alter the main results, which is shown by Smulders and Van de Kumder (1995), and Minniti (2006). In terms of the data, Dunn et al. (1988) indicate that 93.4\% of all firms are single-product firms by using 4-digit SIC data. By employing 5-digit SIC data, Bernard, Redding and Scott (2010) show that 61\% of firms are single-product firms. This assumption then does not lead our model to significantly lose its generality.
Assume that the proportion $\xi_Z$ of the in-house R&D investment and the proportion $\xi_X$ of the production cost are subject to the CIA constraint. Due to this cash constraint, incumbents have to borrow $\xi_Z L_{Z} + \xi_X L_{X}$ at the rate $i$ from households to finance their R&D investment and production. Accordingly, the net profit of an individual firm $j$ can be expressed as:

$$\Pi_j = p_j X_j - (1 - \xi_X)L_{X} - (1 - \xi_Z)L_{Z} - (1 + i)(\xi_Z L_{Z} + \xi_X L_{X}).$$  \hspace{1cm} (10)$$

The present discounted value $V_j(t)$ of net profit is given by:

$$V_j(t) = \int_t^{\infty} \Pi_j e^{-\int_t^{\tau} r(s)ds} d\tau.$$  \hspace{1cm} (11)$$

The firm chooses the paths of its product price $P_j$ and its R&D expenditure $L_{Z}$ to maximize (11), subject to the demand function (6), production cost (8), and the R&D production function (9).

### 2.2.2 Entry

Entrepreneurs create new varieties to compete with incumbents for market share. To determine the entry and exit of the firm, the value of firm $V_j$ defined by (11) has to be compared with the cost of entry and exit (For simplicity, we, hereafter, refer only to entry). By following Peretto (1998a), we assume that entrepreneurs have to pay a sunk cost of $\frac{1}{\beta}$ units of labor hours in order to enter the market. In the presence of the cash constraint, they have to borrow money to finance the $\xi_N$ proportion of entry cost, i.e., the $\xi_N \frac{1}{\beta}$ units of labor hours. Therefore, the total entry cost measured in terms of labor hours is:

$$\left(1 - \xi_N\right) \frac{1}{\beta} + (1 + i)\xi_N \frac{1}{\beta} = (1 + \xi_N i) \frac{1}{\beta}. \hspace{1cm} (12)$$

The free entry condition requires the value of the firm to be equal to the entry cost, i.e.:

$$V_j = (1 + \xi_N i) \frac{1}{\beta}. \hspace{1cm} (13)$$

By combining the labor requirement for entry $L_N = V_j \dot{N}$ with (13), we further have:

$$\dot{N} = \frac{\beta}{1 + \xi_N i} L_N. \hspace{1cm} (14)$$

From (10) and (13), we can define the loan $B$ for the firms’ R&D and production activities (which appears in the household budget constraint (2)) as $B = \frac{\xi_Z L_Z + \xi_X L_X + \xi_N (1 + \xi_N i) L_N}{iL}$. Hall and Lerner (2010, p. 612) report that in practice more than 50 percent of R&D spending is
wage payments to highly skilled technology workers - highly educated scientists and engineers. The R&D-intensive firms need to hold cash to smooth their R&D spending over time, because most of the resource base of the firms will disappear when such workers leave or are laid off. Thus, as shown in Brown and Petersen (2009), the US firms relied heavily on cash reserves to smooth their R&D spending during the 1998-2002 boom. Our specification exactly captures this observation.

2.3 Monetary Authority

The monetary authority implements a nominal interest rate peg by targeting the nominal level of the interest rate $i$. Let the growth rate of the nominal money supply be $\mu = \frac{\dot{M}}{M}$. Thus, by recalling that $M_m = \frac{M}{P_m L}$, the evolution of money real balances is: $\frac{\dot{M}_m}{M_m} = \mu - \pi - \lambda$. The monetary authority will endogenously adjust the money growth rate $\mu$ to whatever level is needed for the targeted interest rate $i$ to prevail.

To balance its budget, the government (solely represented by the monetary authority) simply returns the seigniorage revenues to households as a lump-sum transfer $T$. Thus, the government budget constraint is given by:

$$T = \frac{\dot{M}_L}{P_m L} = \mu M_m = \dot{M}_m + (\pi + \lambda)M_m.$$ (15)

2.4 General Equilibrium

Households choose $\{C_t, l_t, B_t, M_{mt}\}$ to maximize utility (1), subject to (2) and (3), given $\{r_t, w_t\}$ and policy $\{i_t\}$. The first-order conditions of the household’s maximization problem, reported in Section 2.1, can be summarized as follows:

$$i = r + \pi,$$ (16)

$$l = 1 - \gamma E(1 + \xi c i),$$ (17)

$$\frac{\dot{E}}{E} = r - \rho.$$ (18)

The no-arbitrage condition between assets and money (including the loans for R&D) (16) implies the Fisher equation. Equation (17) refers to a trade-off between labor supply and consumption expenditure. Equation (18) is the standard Euler equation of consumption.
Incumbents choose \( \{p_t(j), L_{zt}(j)\} \) to maximize the present value of profits (11), subject to (6) and (9), given policy \( \{i_t\} \). Entrants make entry decisions, given \( \{V_t(j)\} \), entry cost (12) and policy \( \{i_t\} \). By following Peretto (1998a), it is easy to prove that under certain parameter restrictions, all firms make symmetric decisions. Accordingly,

**Proposition 1.** Assuming \( \theta(\epsilon - 1) < 1 \), the Nash Equilibrium is symmetric, under which the goods prices, returns to in-house R&D, and returns to entry, respectively, are:

\[
p = (1 + \xi X i) h(Z) \frac{\epsilon}{\epsilon - 1},
\]

\[
r_Z = \frac{\alpha}{1 + \xi Z i} \left[ \frac{\theta(\epsilon - 1) LE}{\epsilon N} - (1 + \xi Z i) \frac{L_{zt}}{N} \right],
\]

\[
r_N = \pi \frac{\dot{V}}{V} + \frac{\dot{V}}{V} = \frac{\beta}{1 + \xi N i} \left[ \frac{LE}{\epsilon N} - (1 + \xi Z i) \frac{L_{zt}}{N} \right],
\]

where \( L_{zt} \) is the aggregate employment in the R&D sector.

**Proof**  All proofs are relegated to the Appendix. ■

Recall that \( \theta \) measures the degree of diminishing returns of R&D to production and \( \epsilon \) is the elasticity of substitution of intermediates. Thus, the condition \( \theta(\epsilon - 1) < 1 \) guarantees that the diminishing returns to R&D are high enough so that no firms have the incentive to engage in more R&D than others (see Peretto (1998b) for the details). With this condition, Proposition 1 shows that the returns to R&D positively depend on firm market size, which is the total expenditure \( LE \) times the market share \( 1/N \). In the traditional growth model without market structure, the return to R&D depends only on \( LE \). Any policy that alters \( LE \) will affect the returns to R&D and therefore the balanced growth rate. This implies a scale effect. In our model, the market share \( 1/N \) is endogenously determined by the firm’s entry decision. Thus, a policy which alters \( LE \) will also lead to an adjustment of \( N \) accordingly, while leaving \( LE/N \) unchanged. As is evident, the endogeneity of the market structure in this model allows for the discussion on how a policy affects the market structure \( (N) \) and therefore \( LE/N \), such that the returns to R&D and the growth rate are affected, which cannot be done using the other types of models.

The model generates three different growth regimes: the regime with only in-house R&D, the regime with only firm entry, and the regime with both. This study focuses on the regime with both in-house R&D and entry, because in practice both incumbents and new establishments
make a contribution to the TFP growth. Bartelsman and Doms (2000) and Foster and Krizan (2000) document that incumbents account for about 75% of average TFP growth at the industry level, with the remaining productivity improvements being accounted for by the entry of new establishments. Thus, by modifying Peretto’s (1998a, b) condition, we impose the following parameter restrictions:

\[
\alpha > \alpha \theta (\epsilon - 1) > \frac{1 + \xi Z_i}{1 + \xi N_i} \beta.
\]

Unlike Peretto (1998a, b), our restriction indicates that the market structure depends not only on the real productivity of labor and the effectiveness of R&D, but also on the strength of the monetary constraints. Two complements are worth noting here. In the Peretto (1998a, b) models, \( \alpha > \beta \) is a necessary condition to ensure that the regime with both types of R&D is a stable Nash equilibrium. This condition requires that the productivity of labor in the quality-improved R&D (incumbents) must be larger than that in the variety-expanded R&D (entrants). This requirement seems to be strong; in reality it is not necessary for the productivity of an incumbent to be larger than that of an entrant. In this monetary model, the corresponding stability condition is \( \alpha > \frac{1 + \xi Z_i}{1 + \xi N_i} \beta \), implying that the productivity of an entrant can be larger than that of an incumbent, provided that the entrant incurs a higher cash constraint (\( \xi N > \xi Z \)).

In addition, although our analysis focuses on the regime in which both in-house R&D and entry are active, the monetary innovation may lead to a switch from the regime to another one. For example, given the symmetric Nash equilibrium condition \( \theta (\epsilon - 1) < 1 \), if \( \xi Z > \xi N \), a sufficiently large increase in the interest rate could make the in-house R&D become more expansive than the entry, which may stop the firm from devoting resources to in-house R&D. Thus, the regime with both R&D and entry will switch to the regime with entry only, as in a variety-expansion model.

To ensure the market-clearing condition of the goods market, the total supply of goods measured by labor cost is equal to the total demand measured by household expenditure based on (6) and (19), i.e.,

\[
L_X = N L_{X_i} = \frac{\epsilon - 1}{\epsilon} \frac{LE}{1 + \xi X_i}.
\]

In addition, the market-clearing condition of the financial market leads to \( r = r_Z = r_N \). Accordingly, setting (20)=(21) yields:

\[
L_Z = \frac{LE}{\epsilon} \frac{\frac{\alpha}{1 + \xi Z_i} \theta (\epsilon - 1) - \frac{\beta}{1 + \xi N_i}}{\alpha - \frac{1 + \xi Z_i}{1 + \xi N_i} \beta}.
\]
Finally, the labor market clears implying that

\[ Ll = LN + LZ + LX, \]  

(25)

where \( LZ = \int_0^N L_{Zj}dj = NL_{Zj}, \) \( LX = \int_0^N L_{Xj}dj = NL_{Xj}, \) and \( l \) is reported in (17).

### 3 Monetary Policy and Economic Growth

In this section, we solve the dynamic system and then analyze both the steady-state and transition effects of an increase in the nominal interest rate. Define firm size as \( s = \frac{L}{N}, \) the TFP growth as \( g = \theta \frac{\dot{Z}}{Z}, \) and the consumption growth as \( g_C = \frac{\dot{c}}{c} - 1 \). Combining (24) and (9), we have

\[ g = \alpha \theta \frac{LE}{\epsilon N} \left[ \frac{\alpha}{1+\xi N} \theta (\epsilon - 1) - \frac{\beta}{1+\xi N} \right]. \]  

(26)

It is clear from the above equation that the TFP growth is related to the firm’s market size (i.e., \( \frac{LE}{N} \)), the competition parameters between incumbents and entrants (\( \alpha, \beta, \theta, \epsilon - 1 \)), and with a particular emphasis, to the distinct liquidity constraints (\( \xi_Z \) and \( \xi_N \)) on the R&D activities. Of importance, with an endogenously-determined \( N \), the TFP growth depends on the firm’s market size \( \frac{LE}{N} \), rather than the aggregate market size \( LE \). This scale-invariant property is an important difference from the first-generation Schumpeterian models without market structure in which the TPF growth depends on the aggregate expenditure. This also differs from other types of growth model (e.g., the semi-endogenous model), which eliminate the scale effect through simple mathematical revisions in R&D functions, leaving the number of firms to be exogenously fixed by "creative destruction" (in the sense that new firms with better technology replace old firms with backward technology). Instead, (26) indicates that, other things being equal, \( g^* \) negatively depends on entry productivity \( \beta \), implying that the proliferation of product varieties reduces the effectiveness of R&D aimed at quality improvement, by causing it to be spread thinly over a larger number of products. This, on the one hand, endogenizes the market structure (the firm and market sizes) and, on the other hand, eliminates the scale effect. Laincz and Peretto (2006) have shown that data on US employment, R&D personnel and production establishments support the idea that the scale effect is sterilized by product proliferation.

Given (26), by using the optimal labor supply (17), labor requirement for production (23), labor clearing condition (25), free entry condition (14), no-arbitrage condition that (21)=(20), and Euler equation (18), we can reduce the whole dynamic system to the following two differential equations in terms of \( g \) and \( s \):
\[
\dot{s} = \frac{\lambda}{1 + \xi N} (s - \frac{g}{\alpha \theta} \Omega), \tag{27}
\]
\[
\dot{g} = \frac{g}{\alpha \theta} \frac{\beta}{1 + \xi N} \left\{ \frac{\alpha [1 - \theta (\epsilon - 1)]}{1 + \xi N} \frac{1}{\theta (\epsilon - 1)} + \Omega \right\} - \rho + \lambda - \frac{\beta}{1 + \xi N} s, \tag{28}
\]
where \( \Omega = \frac{\gamma (1 + \xi \iota) (\alpha - \frac{1 + \xi X}{1 + \xi N \beta})}{\sigma + \xi N \iota (\epsilon - 1) - \frac{\beta}{1 + \xi N}} \). Accordingly, the loci of the system are given by:

\[
\dot{s} = 0 \Rightarrow g = Q_1 (s - \frac{1 + \xi N \iota}{\beta} \lambda), \tag{29}
\]
\[
\dot{g} = 0 \Rightarrow g = Q_2 [s + \frac{1 + \xi N \iota}{\beta} (\rho - \lambda)]. \tag{30}
\]
Note that \( Q_1 \) and \( Q_2 \) are complicated functions of \( \iota \) and \( \xi q, q = (Z, N, X, C) \), which are relegated to the Appendix. From (29) and (30), the phase diagram can be expressed in Figure 1.

### 3.1 Steady-State Effects

In the steady state, the TFP growth rate \( g^* \) and the ratio of the labor force to the number of firms \( s^* \) are solved by setting \( \dot{s} = 0 \) and \( \dot{g} = 0 \). Given these, the steady-state inflation rate \( \pi^* \) is determined by (16) and (18) with \( \dot{E} = 0 \), while the consumption expenditure per capita \( E^* \) is determined by the market-clearing condition of the financial market (20) = (21) with (9). With the steady-state \( s^* \) and \( E^* \), we can use (17) to pin down the steady-state employment rate \( l^* \).

Finally, given that \( g_C = \frac{\epsilon}{\epsilon - 1} \frac{N}{N} + \frac{\xi_i}{\alpha} \), the steady-state growth rates of entry \( \left( \frac{N}{N} \right)^* \) and consumption \( g_C \) can further be determined by using (14), (23), (24), and (25). See the Appendix for the detailed deduction.

All results are summarized in Proposition 2.

**Proposition 2.** There is a nondegenerate, competitive equilibrium of growth, which is stable and unique. On the growth path,

\[
g^* = \theta \rho \frac{1}{\beta} \frac{\alpha [1 + \xi X \iota]}{1 - \theta (\epsilon - 1)} \left[ \frac{(\alpha [1 + \xi X \iota] \theta (\epsilon - 1) - \beta}{1 - \theta (\epsilon - 1)} \right], \tag{31}
\]
\[
s^* = \left( \frac{L}{N} \right)^* = \frac{1 + \xi N \iota}{\beta} \left\{ \rho \left[ \frac{V_1 + V_2}{\alpha [1 - \theta (\epsilon - 1)] (1 + \xi X \iota)} \right] + \lambda, \right. \tag{32}
\]
\[ l^* = \frac{(1 + \xi_X i)V_2 + V_3 + \alpha[1 - \theta(\epsilon - 1)]\frac{1}{\beta}(1 + \xi_X)}{(1 + \xi_X i)[V_1 + V_2 + \alpha[1 - \theta(\epsilon - 1)]\frac{1}{\beta}]} + V^*_3, \quad (33) \]

\[ \left(\frac{\dot{N}}{N}\right)^* = \lambda, \quad (34) \]

\[ g_C^* = \frac{\dot{C}}{C} = \frac{\epsilon}{\epsilon - 1} \lambda + \theta \rho \frac{1 + \xi_X i}{\beta} \frac{V_2}{1 - \theta(\epsilon - 1)}. \quad (35) \]

\[ E^* = \frac{\epsilon(\alpha - \frac{1 + \xi_X i}{1 + \xi_N i} \beta)(1 + \xi_X i)}{(1 + \xi_X i)[V_1 + V_2 + \alpha[1 - \theta(\epsilon - 1)]\frac{1}{\beta}]} + V^*_3 \quad (36) \]

\[ \pi^* = i^* - \rho, \quad (37) \]

where \( V_1 \equiv \gamma(1 + \xi_C i)\epsilon(\alpha - \frac{1 + \xi_Z i}{1 + \xi_N i} \beta) \), \( V_2 \equiv \frac{\alpha}{1 + \xi_Z i} \theta(\epsilon - 1) - \frac{\beta}{1 + \epsilon_N i} \), and \( V_3 \equiv (\epsilon - 1)(\alpha - \frac{1 + \xi_X i}{1 + \xi_N i} \beta) \).

We are ready to investigate how an increase in the nominal interest rate \( i \) can have different effects on the long-run economic performance through various CIA constraints. Based on Proposition 2, we use Figures 2-4 to present the results of the comparative statics and establish the following corollaries.

**Corollary 1.** With a CIA constraint on in-house R&D \( (\xi_Z > 0, \xi_X = \xi_C = \xi_N = 0) \), a higher nominal interest rate \( i \) decreases the steady-state firm size, TFP growth rate and consumption growth rate, while it increases the inflation rate. In addition, it has an ambiguous effect on employment and consumption expenditure per capita.

As predicted by the Fisher equation, a higher nominal interest rate \( i \) increases the long-run inflation rate shown in (37). A higher inflation rate raises the cost of holding money and hence reduces real money balances in the economy. If the money balances are required to engage in in-house R&D and entry investment is not restricted by such a constraint, in-house R&D becomes more expensive compared to firm entry. By referring to (21) and (20), a higher \( i \) makes both \( r_Z \) and \( r_N \) decrease, but \( r_Z \) decreases more than \( r_N \) (i.e., \( r_Z < r_N \)). Therefore, the economic (labor) resource shifts away from the quality improvement-type to the variety expansion-type innovation. This implies that the number of firms expands faster than the population \( (\dot{N}/N > \lambda) \) and the firm size \( (L/N) \) (or the firm’s market size \( LE/N) \) thereby shrinks. In the steady state, small-sized firms engage in less in-house R&D, which decreases
the rate of innovation growth shown in (9). Since the consumption growth $g_C$, as indicated in (36), is a weighted sum of the TFP growth $g$ and the growth rate of entry $\dot{N}/N$ (which is equal to $\lambda$ in the steady state), the consumption growth rate decreases as well. This negative growth effect is similar to that of Chu and Cozzi (2013), while the underpinning mechanism is rather different.

In addition, the response of equilibrium employment $l^\ast$ could be negative or positive. A higher $i$ restricts the in-house innovation, being in favor of the entrant. While labor resources shift away from R&D and production to entry, this labor reallocation has an ambiguous impact on the total employment. Thus, as shown in (25), the equilibrium employment may be either increasing or decreasing in the nominal interest rate. Moreover, it is clear from (17) that there is a trade-off between consumption expenditure and labor supply. Thus, the steady-state consumption expenditure changes in the opposite direction to employment and has an uncertain response to a change in monetary policy. Interestingly, a higher nominal interest rate may increase the consumption expenditure per capita, even though it gives rise to a negative effect on the long-run consumption growth rate. When a higher $i$ reduces the TFP growth, less R&D makes the (quality-adjusted) price of goods decrease more slowly than in the case without the policy change. Therefore, households consume less, but may incur higher expenditure.

**Corollary 2.** With a CIA constraint on firm entry investment ($\xi_N > 0$, $\xi_X = \xi_C = \xi_Z = 0$), a higher nominal interest rate $i$ increases the steady-state firm size, inflation, employment, and the growth rates of TFP and consumption, but decreases the consumption expenditure per capita.

If entry investment is subject to the CIA constraint, raising the nominal interest rate decreases the real money balances in the economy, owing to a rise in inflation, which restricts the variety-expanded innovations. This decreases $r_N$, keeping $r_Z$ unchanged, as shown in (21) and (20). Because $r_N < r_Z$, the resource shifts from entry to R&D and production, which leads to $\dot{N}/N < \lambda$ and increases firm size. The expansion in firm size further leads to more in-house R&D, resulting in higher growth rates of TFP and of consumption expenditure. In a Schumpeterian model, to gain a higher growth rate, some degree of monopoly power is needed to act as the reward accruing to the successful firms from their innovations. Based on this logic, our monetary model suggests that if entry investment is subject to a higher degree of cash constraint, a rise in the nominal interest rate renders the existing innovators with a larger

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13 A large body of empirical research has indicated that larger size can foster productivity growth because it allows firms to take advantage of the increasing returns associated with R&D. See, for example, Cohen and Klepper (1996a) and more recently Pagano and Schivardi (2003).
degree of monopoly power by increasing entry costs to potential competitors. Thus, high inflation can be associated with higher growth and the Mundell-Tobin effect occurs. Such a case could be empirically plausible, as the evidence shows that R&D is more likely to be liquidity constrained for young or new firms.\footnote{See Janiak and Monteiro (2011) for a discussion on the CIA constraint on new establishments.} This result is in contrast to the findings of Funk and Kromen (2010), who predict a negative growth effect of inflation.\footnote{In addition to the cash/liquidity constraint, the evidence (e.g., Harhoff, 1988) also shows that younger firms (or entrants) are more likely to be constrained by the availability of finance (i.e., the borrowing/financial constraint) due to the moral hazard problem and uncertainty. To capture this observation, a simple way is to modify equation (12) as: $(1 - \xi_N)^{\frac{1}{2}} + [1 + i(1 + \phi)]\xi_N^{-\frac{1}{2}}$, where $\phi$ is a risk premium, reflecting the difficulty of finance for an entrant in a financial market with friction. Thus, there are two different interest rates, which reflect lending to incumbents and entrants. Given a constant rate of risk premium, our main results are robust to this modification.} By contrast, in a money-in-utility-function model, Chu and Lai (2013) find that the growth-inflation relationship could be positive, provided that the elasticity of substitution between money and consumption is larger than one.

The equilibrium employment increases with the nominal interest rate. As shown in (14), a higher $i$ decreases the productivity of entry. Thus, more labor resources are required for entry to maintain the original entry rate, since the steady-state entry growth must be fixed at the population rate (i.e., $(\frac{\dot{N}}{N})^* = \lambda$). This gives rise to a positive direct effect, increasing entry labor and hence total employment. On the other hand, in face of a higher $i$ entry becomes unfavorable, owing to $r_N < r_Z$. Therefore, labor resources move away from entry to R&D and production. Although this labor reallocation effect may have a negative impact on the total employment, it is dominated by the direct entry effect. As a result, the steady-state total employment $(\dot{t})^*$ unambiguously increases in response to a higher interest rate. In addition, as mentioned above, the consumption expenditure per capita changes in the opposite direction of employment and hence decreases in the steady state. While consumption expenditure decreases, the consumption growth rate increases. When entry is restricted by the CIA constraint, a higher $i$ renders the incumbents with an effective shield against potential competition, which motivates them to engage in more in-house R&D. The expansion in the R&D decreases the price of (quality-adjusted) goods and therefore households can enjoy more consumption by incurring less expenditure.

**Corollary 3.** With a CIA constraint on manufacturing production ($\xi_X > 0$, $\xi_N = \xi_C = \xi_Z = 0$), a higher nominal interest rate $i$ decreases the steady-state firm size and employment, but increases the inflation rate. Moreover, it has no effect on the TFP and consumption growth rates.

If manufacturing production is subject to the CIA constraint, a higher nominal interest rate
raises the inflation and decreases the real money balances, which leads to higher production costs. As shown in (19), this further raises the good price $p$. In the face of a higher price, the households are inclined to decrease their consumption and increase their leisure time. Thus, employment falls as a response.\textsuperscript{16} Note that due to a higher price, consumption decreases, but the aggregate consumption expenditure increases.\textsuperscript{17} When the aggregate consumption expenditure (the aggregate market size) rises, entry becomes profitable, which attracts more new firms to enter the market, expanding the product variety. Thus, entry, on the one hand, erodes the incumbents’ profits and, on the other hand, decreases the firm size $s = \frac{L}{N}$. It turns out that the expansion in consumption expenditure $E$ is eroded by entry, leading the firm’s market size $\frac{LE}{N}$ to remain constant. As a result, (26) indicates that the TFP growth rate (and hence the consumption growth rate) is irresponsible to the increase in the nominal interest rate.

Even though both models are scale free, our result contradicts that of Chu and Cozzi (2013), which shows that raising the nominal interest rate permanently increases the growth rate, if manufacturing production is subject to the CIA constraint. However, our model with the endogenous market structure predicts that a higher interest rate only has a positive transitional effect (this will be shown in the next subsection), but no long-run steady-state effect on growth. The Chu and Cozzi (2013) model eliminates the scale effect by re-scaling the firm level innovation arrival rate by population size and normalizing the number of firms to unity. When manufacturing production is subject to the CIA constraint, a higher interest rate shifts labor from the manufacturing to the R&D sector. Since the number of firms is fixed at unity, the rise in the R&D labor share directly increases the arrival rate of the new firms to replace the old firms in the same product line, which in turn stimulates economic growth. In our model with an endogenous number of firms, the firm’s profitability stemming from the expansionary consumption expenditure (caused by the CIA constraint on production) will attract new firms to enter the market. Since entry erodes the profitability, the monetary shock has no effect on growth.

For ease of comparison among the cases, we summarize the comparative statics above in Table 1. The table shows that a higher nominal interest rate is associated with a higher inflation rate in all cases. However, economic growth can increase, decrease or be neutral to the nominal interest rate, depending on the strength of distinct cash constraints. That is, our model gives rise to a mixed long-run relationship between growth and inflation. This is consistent with the non-monotonic output/growth-inflation relationship found by recent empirical evidence, such as Bullard and Keating (1995), Bruno and Easterly (1998), and Ahmed and Rogers (2000).

How does the government’s monetary policy affect the market structure? It is clear from

\textsuperscript{16}From (17) we learn that a rise in consumption expenditure $E$ results in a decrease in employment $l$.

\textsuperscript{17}This implies that the household's demand is relatively inelastic in the model.
Table 1: Comparative Statics Results

<table>
<thead>
<tr>
<th>CIA constraint on in-house R&amp;D</th>
<th>$g^*$</th>
<th>$s^*$</th>
<th>$g_C^*$</th>
<th>$l^*$</th>
<th>$(\frac{N}{N})^*$</th>
<th>$\pi$</th>
<th>$E^*$</th>
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<tbody>
<tr>
<td>CIA constraint on entry</td>
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<tr>
<td>CIA constraint on consumption</td>
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</table>

Table 1 that the various CIA constraints end up with very different market structures. Targeting a higher nominal interest rate is unfavorable to the variety expansion-type R&D, if entry investment is subject to a relatively high cash constraint. Under such a situation, the market is characterized by a small number of large-sized firms. By contrast, a higher $i$ is unfavorable to the quality improvement-type R&D and production, if in-house R&D or production is restricted by a larger cash constraint. As a result, the market is characterized by a large number of small-sized firms. These outcomes all differ from the finding of Wu and Zhang (2001). By simply linking inflation to the firm’s markup, they find that at higher rates of inflation firms are fewer and smaller in size. In spite of their differences, these results point out that in addition to the conventional anti-trust policy and/or regulatory reform, monetary policy can also be used to govern the market structure (in particular, in a R&D-intensive economy). With these distinct theoretical predictions, an interesting testable hypothesis is to empirically examine the relationship between the firm size and monetary policy (or inflation).

In a second-generation growth model with the CIA constraint on only consumption, Chu and Ji (2012) examine the effects of monetary policy. Our model which consists of various cash constraints is apparently more generalized than theirs. Proposition 2 can easily recover their results by setting $\xi_C > 0$ and $\xi_X = \xi_Z = \xi_N = 0$.

**Remark 1**

Chu and Ji (2012) find that growth is immune to monetary policy, but the equilibrium employment is responsive. The money supernerallity on growth contradicts the traditional CIA growth model with flexible labor (e.g., Gomme 1993 and Wang and Yip 1992), which refers

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\[18\] This prediction is not a guide for policy-makers to block all new firms and new products to maximize per capita growth. We attempt to highlight that inflation stemming from raising the nominal interest rate can end up with very different consequences via distinct liquidity constraints, although it seems conventionally like a uniform tax, giving rise to a uniform effect on the economy. Table 1 has potentially pointed out that in the presence of various cash constraints raising the nominal interest rate to block all potential entrants cannot maximize growth. For a second-generation growth model, we need the structure of monopolistic competition in order to maintain both horizontal and vertical dimensions of technology space, which remove the scale effect. If there is just one variety, the model structure will break down to a monopoly, which is abstracted from our analysis.
to a negative effect of inflation on growth. Based on this generalized model, we complement their study and provide new insights to the literature. Due to the property of scale-invariance, in response to a unified monetary policy the relationship between employment and growth is non-monotonic. As shown in Table 1, the employment-growth relationship could be either positively related (as in the case with the CIA constraint on in-house R&D or entry), negatively related (as in the case with the CIA constraint on in-house R&D), or independent (as in the case with the CIA constraint on production and consumption). This outcome also differs from that of the first-generation growth models with the scale effect, which predict a positive employment-growth model. Nonetheless, our results seem to be consistent with the mixed findings of empirical studies. For example, Bean and Pissarides (1993) find that there is little evidence of a robust bivariate relationship between the employment and growth rates during the period of the 1950s-1980s. Gordon (1997) offers an empirical possibility of a negative employment-growth relationship.

### 3.2 Transition Effects

We now turn to the transition effects of monetary policy. From (29) and (30), we have:

\[
\frac{\partial Q_1}{\partial i} = \left[ -\frac{\partial (1+\xi Z)}{\partial i} \frac{(1+\xi N)}{\partial i} A - B \right] \cdot D_1^2; \tag{38}
\]

\[
\frac{\partial Q_2}{\partial i} = \left[ -\frac{\partial (1+\xi Z)}{\partial i} \frac{(A + A') - (B + B')}{\partial i} \right] \cdot D_2^2, \tag{39}
\]

where \(A, B, A', B', D_1\) and \(D_2\) are all complicated combinations of parameters, whose exact expressions are relegated to the Appendix. As shown in the Appendix, they are all positive and \(D_1 > D_2\). We can also easily see that \(\frac{\partial Q_1}{\partial i} < 0, \frac{\partial Q_2}{\partial i} < 0\) under the case with the CIA constraint on in-house R&D (\(\xi Z > 0\) and \(\xi X = \xi C = \xi N = 0\)), while \(\frac{\partial Q_1}{\partial i} > 0, \frac{\partial Q_2}{\partial i} > 0\) under the case with the CIA constraint on either entry (\(\xi N > 0\) and \(\xi X = \xi C = \xi Z = 0\)) or production (\(\xi X > 0\) and \(\xi N = \xi C = \xi Z = 0\)). When either R&D or entry is subject to the cash constraint, the condition \(|\frac{\partial Q_1}{\partial i}| < |\frac{\partial Q_2}{\partial i}|\) is true, while when production is subject to the CIA constraint, \(|\frac{\partial Q_1}{\partial i}| > |\frac{\partial Q_2}{\partial i}|\) holds true. These imply that in response to a rise in \(i\) both the \(\dot{g} = 0\) and \(\dot{s} = 0\) loci shift downwards with the former shifting more than the latter under the case with the CIA constraint on R&D only (see Figure 2). By contrast, both the \(\dot{g} = 0\) and \(\dot{s} = 0\) loci shift upwards with the former shifting more (less), if entry investment (production) is subject to the cash constraint, as shown in Figure 3 (Figure 4).\footnote{If only consumption is subject to the CIA constraint, both the \(\dot{g} = 0\) and \(\dot{s} = 0\) loci shift downwards with the former shifting less. See Chu and Ji (2012) for a detailed discussion on this case.} Accordingly, Figures 2-4 (also see
Corollaries 1-3) indicate that a higher nominal interest rate decreases (resp. increases) both the steady-state growth rate and firm size as the R&D investment (the entry investment) is subject to the cash constraint. In the case with the CIA constraint on production, such a policy has a negative effect on the firm size, but no effect on growth.

CIA constraint on in-house R&D

An increase in \( i \) creates a wedge between the returns to R&D and to entry. It is favorable to entry, i.e., \( r_Z < r_N \), if the in-house R&D is restricted by the CIA constraint. Given a predetermined \( N \), economic resources shift out from in-house R&D/production to entry, leading TFP growth \( g \) to jump down on impact (referring to (9)) and the entry rate \( \dot{N}/N \) to jump up (referring to (14)), as shown in Figure 4. Since the number of firms expands faster than the population, the firm size \( s \) decreases along the transitional path. Given that small-sized firms engage in less R&D, this implies that TFP growth \( g \) gradually declines to a lower steady-state rate until the growth rate of the population returns to the steady-state value \( \lambda \).

As noted previously, the consumption growth rate is a combination of TFP and population growth. As a result, the growth rate of consumption may jump up or down on impact, since the population growth rate jumps up, while the TFP growth rate initially jumps down. Afterwards, the consumption growth rate gradually converges to a lower value of the steady state, given that the TFP growth and population growth both gradually decline in transition.

Corollary 1 indicates that in the face of a higher nominal interest rate \( i \) the resource reallocation effect has a mixed effect on the steady-state employment rate \( l^* \). This resource reallocation effect governs employment not only in the long-run steady state, but also in the short-run transition. At the moment of policy change, the predetermined \( N \) is given. Thus, a higher \( i \) shifts the labor resource away from R&D and production (a decrease in \( L_Z \) and \( L_X \)) to entry (an increase in \( L_N \)). Since the labor reallocation is not symmetric in terms of affecting incumbents and entrants, on impact, employment could either jump down or up, and afterwards it monotonically converges to a higher (or lower) steady state, as shown in Figure 4. With regard to the transition of consumption expenditure, (17) demonstrates that its trajectory is opposite to that of employment.

CIA constraint on entry

If entry, instead of R&D, is subject to the CIA constraint, a higher \( i \) leads the entry investment to become more expensive, relative to the in-house R&D. When the resources move away from entry to in-house R&D/production, Figure 5 shows that \( g \) jumps up, but \( \dot{N}/N \) jumps down at
the moment of the policy change. As $\dot{N}/N$ grows more slowly than the population $\lambda$, the firm size $s$ goes up, leading to higher values of $r_Z$ and $r_N$. Therefore, on the one hand, the TFP growth goes up further and gradually converges to a new and higher steady-state value. On the other hand, the entry growth also gradually increases until it returns to the steady state $\lambda$.

As a result of the adjustments of $g$ and $\dot{N}/N$, the consumption growth rate, with a jump on impact, gradually increases to a higher steady-state value. Of particular interest, because more intensive R&D activities decrease the prices of products, households can increase their consumption while incurring less expenditure. That is why the consumption expenditure $E$ exhibits a transitional trajectory, which is just the opposite of that of the consumption growth rate, as shown in Figure 5. In terms of the adjustment of $l$, on impact employment could either jump up or jump down, while in transition it gradually converges to a higher steady state. The reason is that given the predetermined number of firms $N$, at the moment of policy change the positive direct effect is inactive, but the labor reallocation gives rise to a mixed effect on the total employment.

**CIA constraint on production**

If manufacturing production is subject to the CIA constraint, a higher $i$ leads to a higher unit cost of production relative to that of R&D activities. When the resources move away from production to R&D (including both quality-improved and variety-expanded R&D), Figure 6 shows that both the TFP growth $g$ and the entry growth $\dot{N}/N$ jump up at the moment of policy change. Afterwards, since the firm entry grows faster than the population growth $\lambda$, the firm size $s$ shrinks, leading a lower value of $r_Z$ and $r_N$. Lower returns to R&D lead both the TFP growth and entry to slow down and gradually converge to the original steady state levels. Along such transitional adjustments, the growth rate of consumption, which is a linear combination of $g$ and $\dot{N}/N$, jumps up and then gradually goes back to the original steady state. Besides, as the increase in $i$ raises the production costs, the firm is inclined to raise the good price $p$ by using its monopoly power. In the face of a higher price, on the one hand, households’ expenditure $E$ increases and, on the other hand, they substitute consumption for leisure, decreasing working hours. As shown in Figure 6, followed by an increase in the nominal interest rate, consumption expenditure monotonically increases to a new steady state, while employment monotonically decreases to a lower level of steady state.

The transition effects above are summarized in the following proposition.

**Proposition 3.** In response to an increase in the nominal interest rate $i$, the transitional adjustments of the firm size $s$ and the TFP growth $g$ are monotone: both monotonically decrease
(resp. increase) to the steady-state value, if in-house R&D (resp. entry) is subject to the CIA constraint. In either case, along the transition path the consumption growth rate $g_C$, the employment rate $l$, and the consumption expenditure $E$ may mis-adjust from their long-run steady states. If manufacturing production is subject to the CIA constraint, the transitional adjustments are not so rich: the TFP and consumption growth rates jump up and then gradually back to the original values. While the firm size and employment monotonically decrease to new steady states, consumption expenditure monotonically expands to a higher level.

We have so far investigated the case with the cash constraint on either in-house R&D, entry, or production separately. An extended discussion which allows the coexistence of all cash constraints (including a cash constraint on consumption) may be of interest and worth noting.

**Remark 2**

In absence of the CIA constraint on consumption, our analysis shows that the transitional adjustment of economic growth is monotone in the case with the cash constraint on either in-house R&D or entry. It is easy to further show that if both in-house R&D and entry investment coexist and are subject to the same degree of cash constraint ($\xi_N = \xi_Z > 0$ and $\xi_X = \xi_C = 0$), the two conflicting effects cancel each other out and, as a result, monetary policy has no effect on the TFP growth. However, the two effects do not symmetrically affect other variables; employment and market structure are still responsive even though $\xi_N = \xi_Z > 0$.

Is it possible for the TFP growth rate to exhibit an interesting mis-adjustment (in the sense that along the transition path $g$ mis-adjusts from its long-run steady state)? This is an interesting and possibly more realistic case. To this end, we consider the situation where $\xi_C > 0$, $\xi_N > \xi_Z > 0$ and $\xi_X = 0$.\(^{20}\) The condition $\xi_N > \xi_Z > 0$ captures the IO fact that newer firms face a larger cash constraint than older firms. This allows us to generate a positive growth effect of inflation in the long run, as predicted by the Mundell-Tobin effect. The condition $\xi_C > 0$, on the one hand, satisfies the common specification of a CIA model, and on the other hand, enables us to capture the idea of Chu and Ji (2012). If consumption is restricted by a cash constraint, raising the nominal interest rate decreases the real money balances, which in turn lower consumption and employment. If the CIA constraint parameter on consumption $\xi_C$ is significantly high, then the decrease in employment leads the growth rate to jump down in transition.\(^{21}\) Thus, as shown in Figure 6, in response to an increase in $i$, the TFP growth rate rises in the long run, while it falls during the transition.

\(^{20}\)Including the CIA constraint on production merely complicates the derivations without adding significant insights. This mis-adjustment case can also occur if $\xi_X > 0$.

\(^{21}\)See the Appendix for the threshold of $\xi_C$. 

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4 Concluding Remarks

This paper has explored the long-run steady-state and the short-run transition effects of monetary policy on the number of firms, firm market size, inflation and economic growth. A Schumpeterian growth model with an endogenous market structure has been constructed and the macro consequences of inflation have been examined by considering various CIA constraints imposed on in-house R&D (quality-improved R&D), entry investment (variety-expanded R&D), production activities, and consumption. It has been shown that these CIA constraints work through various channels and the effects of monetary policy depend on the strength of each channel. Inflation, which seems like a uniform tax, can give rise to quite different consequences because of different CIA constraints in the economy.

Our comparative statics analysis has shown that if in-house R&D is subject to the CIA constraint, raising the nominal interest rate decreases the firm size and economic growth. In sharp contrast, if entry investment is subject to the CIA constraint, a higher nominal interest rate has opposite effects on these variables. If production or/and consumption is subject to the CIA constraint, growth is irrespective of the increase in the nominal interest rate, while the firm size and employment decrease. In either case, inflation positively responds to such a monetary policy. These results have provided a couple of new implications of relevance to policy. First, the case with the CIA constraint on entry identifies a new channel for the Mundell-Tobin effect. Second, the mixed long-run relationship between growth and inflation can reconcile the recent empirical findings. Third, the identical monetary policy may end up with very different market structures, employment and growth consequences in the presence of distinct cash constraints.

The transition analysis has indicated that in response to a higher nominal interest rate, firm size and TFP growth both monotonically decrease (resp. increase) to the steady-state value, if in-house R&D (resp. entry) is subject to the CIA constraint. However, in either case, along the transition path the consumption growth rate, the employment rate, and the consumption expenditure may mis-adjust from their long-run steady states. When production is restricted by the cash constraint, the dynamics of market structure, employment, and growth are relatively monotonic. In particular, when the CIA constraint on consumption is included and allowed to play a role, the TFP growth rate may also exhibit a mis-adjustment.

As a future agenda, it would be interesting to ask how the monetary policy affects social welfare. Is the Friedman (1969) rule socially optimal in the growth model with an endogenous market structure? Roughly speaking, with a CIA constraint on R&D, a higher $i$ may have an ambiguous impact on welfare. This is because the change in monetary policy makes the TPF growth $g$ (the effect stemming from the quality-improved R&D) and the entry growth $\dot{N}/N$ (the effect stemming from the variety-expanded R&D) move in opposite directions, and thus the response of the consumption growth $g_C$ depends on which force dominates. This ambiguity
potentially implies that a positive nominal interest rate could be desirable to the society and Friedman’s rule is not necessarily optimal. We must bear in mind, however, that this welfare analysis will come at the cost of much greater complexity, due to the complicated effects of the dynamic transitions. To pin down the welfare responses, we will need to further calibrate the related parameters of the model and numerically perform the analysis.
References


Appendix: (A major portion of the Appendix is not intended for publication.)

Proof of Proposition 1:

For the proof of the symmetric condition $\theta(\epsilon - 1) < 1$ the reader can refer to Peretto’s (1998b) Proposition 1. Under this condition, the incumbent chooses the paths of its product price $P_j$ and its R&D expenditure $LZ_j$ to maximize (11) subject to the demand function (6) and the R&D production function (9). By defining $q_j$ as the costate variable, which is the value of the marginal unit of knowledge, this optimization problem is to maximize the following current-value Hamiltonian

$$CVH_j = [p_j - h(Z_j)]X_j - (1 + i\xi X)LX_j - (1 + i\xi Z)LZ_j + q_j,$$

s.t. (6) and (9). The firm’s knowledge stock $Z_j$ is the state variable, while the in-house R&D resource $LZ_j$ and the product price $p_j$ are the control variables. By taking the first-order derivative with respect to $p_j$, we can obtain the optimal price, reported in (19). Moreover, the linear Hamiltonian yields

$$LZ_j = \begin{cases} 0 & \text{for } 1 + \xi Z_i > q_j \alpha K \\ LZ/N & \text{for } 1 + \xi Z_i = q_j \alpha K \\ \infty & \text{for } 1 + \xi Z_i < q_j \alpha K \end{cases}$$

where $1 + \xi Z_i$ is the marginal cost of R&D and $q_j \alpha K$ is the value of the marginal unit of knowledge. The interior solution is determined under the condition that the marginal cost of R&D equals its marginal benefit. The differential equation for the costate variable gives:

$$r_j = \frac{\dot{q}_j}{q_j} - \frac{h'(Z_j)X_j}{q_j},$$

indicating that the return to R&D is the ratio of the revenue from the innovation to its shadow price $(-h'(Z_j)X_j/q_j)$ plus the change in the value of the knowledge stock $(\dot{q}_j/q_j)$. Consider the interior solution and let $g_K = \dot{K}/K$ be the growth rate of public knowledge. Taking logs and
time derivatives of $1 + \xi Z_i = q_i \alpha K$, (6), (7), (8), (9), (19) and $h(Z_j) = Z_j^{-\theta}$ allow us to reduce (40) to (20) under the symmetric equilibrium.

Given entry costs $(1 + \xi_N i)^{\frac{1}{\beta}}$ and the value produced $V_j$, taking logs and time derivatives of the free entry condition (13) yields:

$$r_j = \frac{\pi_j}{V_j} + \frac{\dot{V}_j}{V_j}. \quad (41)$$

This implies that the rate of return on the firm ownership equals the rate of return on the riskless loan of $V_j$. By using (13), (6), (7), (8), (19), and (10), and imposing symmetry, we can reduce (41) to (21).

**Proof of Proposition 2:**

From (29) and (30), it is easy to derive the steady state values of $g$ and $s$, as reported in (31) and (32). From the arbitrage condition (21)=(20), we obtain (24). By recalling that $g = \theta \dot{Z}$ and $\dot{Z} = \alpha K \frac{L_k}{N}$, we then have $g = \theta \alpha \frac{L_k}{N}$ under symmetry (i.e., $Z_j = K$). Using (31), (32) and (24), one can solve the steady state value of $E$ through solving $g = \theta \alpha \frac{L_k}{N}$. By plugging the steady state value of $E$ into the optimal labor supply (17), the steady state value of $l$ can be derived, as shown in (33). The steady-state entry rate (34) can be solved through $\frac{\dot{L}}{L} - \frac{\dot{N}}{N} = \frac{\dot{s}}{s}$, given that $\frac{\dot{L}}{L} = \lambda$ and $\frac{\dot{s}}{s} = 0$ in the steady state.

From (4), we have:

$$g_C = \frac{\epsilon}{1 - \epsilon} \frac{\dot{N}}{N} + \frac{\dot{c}_j}{c_j}. \quad (42)$$

From (6), (8), (23), and (18) and by imposing the symmetric condition $L_X = NL_X$, we further obtain:

$$g_C = \frac{1}{\epsilon - 1} \frac{\dot{N}}{N} + g \left(1 + \frac{\beta}{(1 + \xi_N i)\theta} \left[\frac{\alpha}{1 + \xi Z_i} \theta\epsilon - 1\right] - \frac{\beta}{\theta(\epsilon - 1)}\right) - \rho. \quad (42)$$

The steady state value of $g_C$, reported in (35), is then solved by using (42), (31) and (34). Finally, the steady-state inflation rate is pinned down by the Fisher equation (16).
The Derivatives of $Q_1$, $Q_2$, $A$, $B$, $A'$, $B'$, $D_1$ and $D_2$:

It is easy to obtain these derivatives, which are expressed as follows:

$$Q_1 = \frac{(1 + \xi X i)\alpha \theta V_4}{(1 + \xi X i)((1 + \xi Z i) V_1 + V_4) + (1 + \xi Z i)V_3},$$

$$Q_2 = \frac{(1 + \xi X i)\alpha \theta V_4}{(1 + \xi X i)((1 + \xi Z i) V_1 + V_4 + \alpha(1 + \xi Z i)[1 - \theta(\epsilon - 1)]) + (1 + \xi Z i)V_3},$$

$$A = \gamma(1 + \xi C i)\epsilon + \frac{\epsilon - 1}{1 + \xi X i}(1 + \xi Z i)\alpha[1 - \theta(\epsilon - 1)],$$

$$B = \gamma \xi Z (1 + \xi C i)\epsilon + (\epsilon - 1)\xi Z + \frac{\gamma(1 + \xi Z i)\xi C \epsilon}{1 + \xi X} - \frac{(\epsilon - 1)(1 + \xi Z i)}{(1 + \xi X)^2} \cdot (\alpha - \frac{1 + \xi Z i}{1 + \xi N i} \beta) \cdot V_4,$$

$$A' = (1 + \xi Z i)\alpha[1 - \theta(\epsilon - 1)],$$

$$B' = \alpha \xi Z [1 - \theta(\epsilon - 1)] V_4,$$

$$D_1 = [(1 + \xi Z i) V_1 + V_4 + \frac{(1 + \xi Z i)}{1 + \xi X i} V_4]^2,$$

$$D_2 = \left\{ (1 + \xi Z i) V_1 + V_4 + \alpha(1 + \xi Z i)[1 - \theta(\epsilon - 1)] + \frac{(1 + \xi Z i)}{1 + \xi X i} V_3 \right\}^2,$$

where $V_4 \equiv \alpha \theta(\epsilon - 1) - \frac{1 + \xi Z i}{1 + \xi N i} \beta$. 

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The Threshold of $\xi_C$:

If the cash constraints on in-house R&D, entry investment, and consumption exist simultaneously, in response to a higher nominal interest rate the TFP growth rate could jump down on impact, provided that $\xi_C$ is higher than a threshold such that $\frac{\partial Q_1}{\partial i} < 0$, $\frac{\partial Q_2}{\partial i} < 0$:

$$
\xi_C > \frac{(1 + \xi_Z i)\alpha[1 - \theta(\epsilon - 1)](\gamma + \epsilon - 1)\frac{\xi_N - \xi_Z}{(1 + \xi_Z i)^2} - (\alpha - \frac{1 + \xi_Z i}{1 + \xi_N i} \beta) V_4 \xi Z (\gamma \epsilon + \epsilon - 1) + A' + B'}{(\gamma + 2 \gamma \xi Z i \epsilon)(\alpha - \frac{1 + \xi_Z i}{1 + \xi_N i} \beta) V_4 - \gamma (1 + \xi Z i^2) \alpha[1 - \theta(\epsilon - 1)]\frac{\xi_N - \xi_Z}{(1 + \xi_Z i)^2}}.
$$
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