

Three Essays on Dynamic General Equilibrium Models

Ippei Fujiwara*

Nuffield College, University of Oxford

and

Bank of Japan

* I would like to thank Richard Mash and John Muellbauer for insightful comments and encouragement. Furthermore, helpful discussions with Stefania Albanesi, Kosuke Aoki, David Aikman, David Backus, Tamin Bayoumi, Florin Bilbiie, Martin Bodenstein, Toni Braun, Jeff Campbell, Larry Christiano, Giancarlo Corsetti, Shigeru Fujita, Mark Gertler, Fabio Ghironi, Marc Giannoni, Fumio Hayashi, Christian Hellwig, Dale Henderson, Heedon Kang, Jinill Kim, Nobuhiro Kiyotaki, Keiichiro Kobayashi, Andy Levin, Gian Maria Milesi-Ferretti, Tomoyuki Nakajima, Keisuke Otsu, Joe Pearlman, Paolo Pesenti, Laura Piscitelli, Franck Portier, Antti Ripatti, Masashi Saito, Toshi Sekine, Frank Smets, Justin Svec, Lars Svensson, Mike Woodford, Tack Yun and Feng Zhu are highly appreciated. We also thank conference and workshop participants at the Bank of International Settlement, the Bank of Japan, the Bank of Korea, the Columbia University, the European Central Bank, the Federal Reserve Board, the University of Tokyo, and the Reserve Bank of South Africa for useful suggestions. The views expressed in this thesis should not be taken to be those of the Bank of Japan nor any of its respective monetary policy or other decision making bodies. Any errors are solely the responsibility of the authors.

1 Introduction

In this dissertation, we have written three essays on the dynamic general equilibrium models.

Since the seminal research by Kydland and Prescott (1982), which is based on the neo-classical optimal growth model as in Ramsey (1928), Cass (1965) and Koopmans (1965), the Real Business Cycle models have been developed to explain the aggregate fluctuations. Hansen (1985) and Rogerson (1988) introduce the indivisible labor model to respond to the criticisms on very high labor elasticity. Braun (1994) and McGrattan (1994) show that introduction of distortional taxes can enhance the model's ability to explain the data. Greenwood, Hercowitz and Huffman (1988) endogenize the capital utilization and provide that small technological progress can have very large effects on the macro economy. Burnside and Eichenbaum (1996) incorporate the labor hoarding, under which the utilization rate for labor is time-varying, for the better explanation of the labor dynamics. Benhabib, Rogerson and Wright (1991) introduce the home production to reduce the effects of the wealth effects to the realistic level. Merz (1995) and Andolfatto (1996) apply the theoretical labor search and matching model as in Mortensen and Pissarides (1994) to the business cycle analysis and show such an extended model can explain aggregate fluctuations better than the standard Real Business Cycle models.¹ These developments are very well summarized in King, Plosser and Rebelo (1988a, 1988b) and Cooley (1995).²

¹This leads to the current debate in equilibrium unemployment models as found in Shimer (2005)

²Except for explaining fluctuations, Cole and Ohanian (2002) show that the standard Real Business Cycle with exogenous TFP obtained from data can well explain the Great Depression.

While most of the Real Business Cycle models ignore nominal rigidities and the role of monetary policy as the name suggests, some studies insist the necessities to incorporate these nominal features so that we can construct a model which can represent reality. For example, Galí (1999) and Basu, Fernald and Kimball (2006), focusing on the effects of technological improvements on other macroeconomic variables, especially hours worked, show that the Real Business Cycle models cannot account for the empirical facts while the model with nominal rigidities can. Meanwhile, Bils and Klenow (2004) and following analyses using micro data on price settings, provide the clear evidence on the price stickiness. Christiano, Eichenbaum and Evans (1999) summarize the developments of the VAR models on monetary policy shocks since the seminal work by Sims (1980), and clarify the role of the monetary policy shock in the business cycles. Under such circumstances, models developed by Kimball (1995) and Yun (1996), that incorporate nominal rigidities in the form of the staggered price setting introduced by Calvo (1983), have been receiving much attentions. These models called as the (dynamic) new Keynesian model, the New Neo-Classical Synthesis model, the dynamic IS-LM model, the new IS-LM model, the Neomonetarist model or the Monetary Business Cycle model, are now the work-horse models for policy institutions when forecasting the economy, understanding the aggregate fluctuations and seeking for the optimal monetary policy.³

The core structure of these models consists of three equations, the new Keynesian Phillips curve, the dynamic IS equation and the monetary policy rule. The new Key-

³Open economy models in this tradition initiated by Obstfeld and Rogoff (1995) is called as the New Open Economy Macroeconomics Models.

nesian Phillips curve depicts the aggregate supply condition, namely the relationship between price (inflation) and output. The key feature here is that firms cannot fully adjust their prices optimally all the time. As a result, they take the forward looking behavior in price setting, that is, take the future developments in marginal cost into account. Such stickiness in price setting is usually introduced by using the staggered contracts in Taylor (1979, 1980) and Calvo (1983) or the price adjustment cost in Rotemberg (1982). Taylor (1979, 1980) assumes the staggered contracts for the fixed duration while Calvo (1983) supposes a situation where only fractional firms can re-optimize their prices. Despite their similarities, each specification has quite different welfare implication. For example, while some firms cannot change their price optimally forever in Calvo (1983), no such horizontal relative price distortions but only intertemporal relative price distortions exists in Rotemberg (1982).⁴ Yet, as long as the model is solved in a common framework of the log-linearized system using the technique introduced in Blanchard and Kahn (1980), Roberts (1995) show that specifications of nominal rigidities in Taylor (1979, 1980), Calvo (1983) and Rotemberg (1982) are observationally equivalent.⁵ The dynamic IS equation represents the standard Euler equation for intertemporal substitution, which connects the consumption and real interest rates, and plays important role in the Real Business

⁴Micro evidences on price setting as in Bils and Klenow (2004) point out that many price adjustments are infrequent and large, that is contrary to the implication by Rotemberg (1982).

⁵We employ Rotemberg (1982) type specification in this dissertation. Except for the normative analysis on monetary policy in Chapter 3, results will not change. The reason why we choose the Rotemberg (1982) type specification here is that it is more consistent with firm dynamics.

Cycle models as well. The monetary policy rule is usually employed in the form of the Taylor (1993) rule, in which the policy interest rate is determined by reacting to inflation and output gap, theoretically the deviation of the output from that in the flexible price equilibrium. Before the advent of the Taylor rule, the money growth rule, following the classic Friedman's $k\%$ rule in Friedman (1969), to keep the inflation expectation constant is usually employed as a monetary policy rule. Taylor (1993) showed the Taylor principle where nominal interest rates should be raised more than one-to-one to inflation so that real interest rate and therefore inflation are controlled. Since then, because we know how to avoid indeterminacy with the Taylor rule and the Taylor rule satisfying such a condition, namely the Taylor principle, fits more to the actual exercises taken by the central banks, the Taylor rule has been more used in academic and practical analysis on monetary policy than the traditional money growth rule.⁶

The new Keynesian models, well-summarized in Clarida, Gali and Gertler (1999), Walsh (2003) and Woodford (2003), have been developed in both normative and positive perspectives. Because the new Keynesian model is based on rigid micro-foundations with nominal rigidities, the normative implications of monetary policy has been intensively investigated. Rotemberg and Woodford (1997) derive the quadratic social loss function which is theoretically consistent with micro-founded models. This turns out to take the same form as the traditional objective of the central banks as minimizing the weighted sum of squared deviations of inflation and

⁶In this paper, except for the normative analysis in Chapter 3, we employ the the Taylor rule because this fits the empirical facts very well. The Taylor rule is usually not the optimal rule.

output from their targeted values. This has boosted the analysis on the nature of the optimal monetary policy to minimize such a theoretically consistent welfare criteria. In addition to the above mentioned Clarida et al. (1999), Walsh (2003) and Woodford (2003), Erceg, Henderson and Levin (2000) inquire into the optimal monetary policy when there exist nominal rigidities in both prices and wages. Aoki (2001) show the optimal monetary policy when the degree of nominal rigidities are different among sectors while Aoki (2003) reveal the nature of optimal monetary policy when the potential growth rate is only available with noisy informations. Svensson (2003) emphasize the importance of the optimal monetary policy in the form of the targeting rule instead of the instrument rule as in the form of the Taylor rule. These developments are thoroughly covered in Giannoni and Woodford (2003a, 2003b, 2003c).

Prevalence of the new Keynesian models are not solely from normative perspectives for their usefulness in monetary policy analysis. Rather, some claim that it has come from its explanatory power for business cycles. In a situation where such studies as Galí (1999), Basu et al. (2006), Bils and Klenow (2004) and Christiano et al. (1999) show the problems in empirical accounting in the Real Business Cycle models, Christiano, Eichenbaum and Evans (2005) construct a model with sticky prices and wages, habit formation in consumption and investment growth adjustment costs and show such a model can reproduce the impulse responses for the monetary policy shock obtained in the VARs quite well. Then, Smets and Wouters (2003, 2007) show that such a model estimated by the Bayesian maximum likelihood technique introduced by Schorfheide (2000), can demonstrate similar fits to non-structural VAR models.

These models have now become the core models in many policy institutions as in Adolfson, Laseen, Linde and Villani (2007), Erceg, Guerrieri and Gust (2006) and Laxton and Pesenti (2003). Interestingly, reflecting the popularity of such models, two leading figures on the positive analysis show their cynical views on the prevalence of the new Keynesian models in Fujiwara, Fukuda, Muto, Shigemi and Takahashi (2008a). Mark Gertler of the New York University has commented that “newly developed groupthink might have set the stage for the next global economic contraction, because all the central banks were going to make the same mistakes using the same models.” Furthermore, Lawrence Christiano of the Northwestern University has said that “there was an amazing, probably unhealthy, consensus at the moment as to models and therefore this was an unusual time in economics.” Further developments have been made to the so-called canonical Dynamic General Equilibrium models following Christiano et al. (2005) and Smets and Wouters (2003, 2007). Bernanke, Gertler and Gilchrist (1999) incorporate the financial accelerator mechanism based on the costly state verification model by Townsend (1979). Moreover, to incorporate more realistic expectations than the rational expectation, learning following Evans and Honkapohja (2001) has been intensively applied to the new Keynesian Models.

This thesis aims at contributing to the existing studies in the dynamic stochastic general equilibrium model, particularly in the new Keynesian models, on three aspects. It consists of three chapters. Chapter 2 is on “Dynamic new Keynesian Life-Cycle Model.” Chapter 3 is on “Re-thinking Price Stability in an Economy with Endogenous Firm Entry: Real Imperfections under Product Variety.” Chapter 4 is on “Growth Expectation.” Brief explanations about contributions are as follows.

In Chapter 2, we investigate the macroeconomic responses to such structural shocks on monetary policy and technology in a life-cycle economy both from normative and positive perspectives. This is the first structural analysis on the distributional aspects of the new Keynesian model. Chapter 3 inquires into the optimal monetary policy when firms entry and exit from the market. The new Keynesian model with such extensive margin adjustments in firms are studied in Bilbiie, Ghironi and Melitz (2005, 2006, 2007) and Bergin and Corsetti (2005) from both positive and normative perspectives. They, however, assume that the steady state is efficient, namely the first best allocations are obtained in the non-stochastic steady state. Instead, by assuming the distorted steady state where fiscal policy does not play any role in eliminating the excess profit stemming from monopolistic competition, we can analyze the nature of optimal monetary policy facing the real imperfections namely trade-off between stabilizing inflation and welfare-relevant output gap. One interesting result from Chapter 3 is that under the distorted steady state the optimal inflation is non-zero, which is a new finding. In Chapter 4, we investigate the responses for the anticipation of future high productivity. Christiano, Ilut, Motto and Rostagno (2007a) show that realistic expectation-driven business cycles can be materialized in the so-called canonical dynamic stochastic general equilibrium model as in Christiano et al. (2005) and Smets and Wouters (2003, 2007) for such anticipated shocks. Yet, they only give a one time level increase in productivity as a shock. We show that if we instead assume the anticipation of future higher growth rate of technology, such an expectation-driven business cycle is hardly generated.

Abstracts of each Chapter are as follows.

In Chapter 2, we first construct a dynamic new Keynesian model that incorporates life-cycle behavior *a la* Gertler (1999), in order to study whether structural shocks to the economy have asymmetric effects on heterogeneous agents, namely workers and retirees. We also examine whether considerations of life-cycle and demographic structure alter the dynamic properties of the monetary business cycle model, specifically the degree of amplification in impulse responses. According to our simulation results, shocks indeed have asymmetric impacts on different households and the demographic structure does alter the size of responses against shocks by changing the trade-off between substitution and income effects.

In Chapter 3, we re-think price stability in an economy with endogenous firm entry under possible distortions. We first demonstrate that endogenous entry causes real imperfections. Reflecting fluctuations in the number of varieties, the gap between the natural and the efficient level of output is no longer constant and variant to shocks. As a result, the central bank faces a trade-off between stabilizing inflation and welfare-relevant output gap. Then, we show that this results in the non-zero optimal rate of inflation. We further check whether welfare can be enhanced by targeting welfare-based inflation instead of cross-sectional average inflation contrary to the previous findings. Simulations even with such distortions as unknown natural interest rate or no fiscal remedy for efficient non-stochastic steady states, however, support cross-sectional average inflation targeting although there may exist some small gains by referring also to welfare-based inflation rates. Incomplete stabilization may enhance welfare in an economy when agents cannot internalize the externality on the love for variety.

Chapter 4 is about the difficulty in producing reasonable business cycles for the expectation shock about higher future technology. For a long time, changes in expectations about the future have been thought to be significant sources of economic fluctuations, as argued by Pigou (1926). Although creating such an expectation-driven cycle (the Pigou cycle) in equilibrium business cycle models was considered to be a difficult challenge, as pointed out by Barro and King (1984), recently, several researchers have succeeded in producing the Pigou cycle by balancing the tension between the wealth effect and the substitution effect stemming from the higher expected future productivity. Seminal research by Christiano et al. (2007a) explains the “stock market boom–bust cycles,” characterized by increases in consumption, labor inputs, investment and the stock prices relating to high expected future technology levels, by introducing investment growth adjustment costs, habit formation in consumption, sticky prices and an inflation–targeting central bank. We, however, show that such a cycle is difficult to generate based on “growth expectation,” which reflect expectations of higher productivity growth rates. Thus, Barro and King’s (1984) prediction still applies.

2 Dynamic New Keynesian Life–Cycle Model⁷

2.1 Introduction

Societal aging is one of the biggest economic issues facing many industrial countries. In Japan, in particular, society is aging so rapidly that not only is the working population (those older than 15 but younger than 65) already shrinking, but the total population is also expected to start decreasing by 2007. This movement suggests that the central bank should have an even greater interest in how monetary policy affects heterogenous agents, namely workers and retirees, differently and how the consideration of this demographic structure may alter the reaction of variables to structural shocks.⁸ Seminal research by Woodford (2003) depicts the various forms of the dynamic new Keynesian model corresponding to different economic conditions and has had a significant influence on central banks' views of monetary business cycle. However, to date very little research has paid attention to monetary business cycle model with heterogenous agents, particularly within a life–cycle setting.

In this paper, we first set up a dynamic stochastic general equilibrium model with nominal rigidities and investment adjustment costs that incorporates life–cycle

⁷This paper is co-authored with Yuki Teranishi. This chapter is published as an article in *Journal of Economic Dynamics and Control* 32 (8).

⁸For example, “The Coming Demographic Transition: Will We Treat Future Generations Fairly,” the chairman, Ben Bernanke, discusses the societal ageing and comments that “the broader perspective shows clearly that adequate preparation for the coming demographic transition may well involve significant adjustments in our patterns of consumption, work effort and saving,” although the remarks are mainly on the sharing the burden of population ageing.

behavior *a la* Gertler (1999). Then, we show whether the structural shocks to the economy have asymmetric effects on heterogeneous agents and whether the considerations of the life-cycle and demographic structure alter the dynamic properties of the solution, under different settings of life-cycle behavior.⁹ Of course, as mentioned in Bean (2004), it is true that “the glacial nature of demographic change appears to suggest that the implications for monetary policy should be modest.” We, however, believe that it becomes more important for central banks to acknowledge the asymmetric effects on heterogeneous agents within a life-cycle economy with a stationary population, since societal aging in many industrial countries necessitates the consideration of the distributional consequences of monetary policy. Furthermore, central banks must always understand the monetary transmission mechanism as well as macroeconomic responses to structural shocks in detail. Therefore, we focus on the impulse responses of this life-cycle economy. We know that the impact of societal aging on general equilibrium has two separate aspects, and it is important to distinguish between the two. First, the “transition” toward the aging society can be most naturally considered in terms of a macro shock, which will affect monetary policy decisions. Second, the impulse responses derived from a dynamic new Keynesian model in a “stationary population” may be quite different for an elderly society than

⁹This aim is similar to those in recent literature on real rigidities that try to explain realistic inflation persistence with reasonable calibration, such as Sveen and Weinke (2005), Altig, Christiano, Eichenbaum and Linde (2005), and Levin, Lopez-Salido and Yun (2007). Yet, the demographic structure does not alter the persistence but the volatility of the endogenous variables against structural shocks.

for a young society. For the purposes of the current paper, we focus on the second of these two aspects.

Bean (2004) summarizes the previous findings in this field, pointing out their implications for a central bank: (1) demographic developments represent a macroeconomic shock, which may lead to abrupt movements in asset prices and sharp movements in saving behavior; (2) the natural rate of interest falls both along the transition path and in the steady state; (3) the natural rate of unemployment may also be affected through the matching mechanism;¹⁰ (4) the wealth channel is likely to become a more important transmission channel of monetary policy than intertemporal substitution; (5) the Phillips curve is flatter due to immigration and the increased participation of retired workers whose supply of labor is considered to be relatively elastic; (6) the constituency for keeping inflation low will be larger thanks to higher average wealth accumulation; and (7) societal aging may induce diversification and risk-shifting with a securitized market rather than bank-intermediated finance, which has implications for financial stability. Although not all the topics raised by Bean (2004) can be covered in this paper, we formally verify (4) using the dynamic general equilibrium model with sticky price and life-cycle behavior. Yet, as societal aging deepens, although income effect becomes stronger for retirees, that of workers becomes weaker. Hence, in aggregate, a tightening monetary policy shock still has negative impacts on the aggregate demand. Even though retiree's consumption increases, worker's consumption or the investment needs to be lowered

¹⁰We would like to consider incorporating matching mechanism similar to Merz (1995) and An-dolfatto (1996) in our future research.

since there is no expansion in the production frontier. At the same time, we will show that (2) is not a general result due to the endogenized labor participation by retirees. Furthermore, we find that since retirees do not work as much as workers, they benefit less from improved technology, a point not raised by Bean (2004). Therefore, the monetary response to a positive technology shock can be smaller in a greyer society. Anecdotal evidence on these points abounds, but there have been very few studies that have tackled this problem in a theoretically consistent dynamic general equilibrium framework, which is the workhorse model for modern monetary policy analysis. Our main conclusions are as follows. Since retired people rely more on interest income than on wages from their labor supply, shocks indeed have different impacts on different households. Furthermore, the demographic structure does alter the size of the response to shocks by changing the degree of the trade-off between substitution and income effects. Therefore, societal aging and life-cycle considerations, have important implications for monetary policy.

Another interesting point is to compare optimal monetary policy in this life-cycle economy to the one obtained in a standard model with homogeneous agents. Stochastic welfare analysis, however, raises difficult issues such as what discount rate should be used by firms and which welfare measures are appropriate with the setting of the model in this paper. As for the latter, it is not trivial to compute aggregate welfare with heterogeneous agents. In other words, it is difficult to weigh the welfare of each heterogeneous agent in order to obtain aggregate welfare measure. The former is an especially large concern with incomplete markets and heterogeneous agents, because marginal utility growth rates are no longer equalized across agents and therefore the

choice of the appropriate discount factor is no longer obvious.¹¹ Thus, we restrict our analysis to the case of perfect foresight with one-time unanticipated shocks that may be auto-correlated as examined in Ghironi (2006), Kilponen and Ripatti (2006), and Kilponen, Kinnunen and Ripatti (2006). In a perfect-foresight setting, all assets including the one-period bond must yield the same return. As a result some very difficult (and as yet unsolved) problems regarding asset valuation can be sidestepped.

This paper is put together as follows. In Section two, we describe the model employed in this analysis. Then, Section three discusses the nature of our stationary population under different demographic structures. We show that the natural rate of interest is quite different among the different demographic setups. In Section four, we show the impulse responses and show that shocks indeed have different impacts on different households and the demographic structure does alter the size of responses to shocks by changing the trade-off between substitution and income effects. Finally, Section five concludes.

2.2 Literature Review

Although money has been an important research agenda in the overlapping generations model introduced by Samuelson (1958),¹² very little research has paid attention

¹¹One solution is to use a discount factor that is a weighted average of the marginal utility of wealth of each group of agents with the group weights given by the relative share holdings as examined in Heathcote and Perri (2004) for foreign and domestic shareholders.

¹²They are thoroughly summarized in Champ and Freeman (2001).

to monetary business cycle model or new Keynesian model with heterogenous agents. Several related researches are as follows.

Williamson (2005) analyzes monetary policy and resulting distribution in an island economy. Furthermore, Doepke and Schneider (2006) show that young borrowers benefit more from inflation than retirees, and inflation can be welfare-enhancing since it acts like a tax on foreign share holders. Miles (2002), based on the standard overlapping generations model, has similar interests to ours. Their analyses are, however, not based on the canonical dynamic new Keynesian model, heavily used among central banks. Therefore, it is not very easy to derive practical policy prescriptions directly from those studies.¹³

As a large-scale dynamic general equilibrium model used for central bank projections and policy simulations, Kilponen, Ripatti and Vilmunen (2004) construct a model with lifecycle behavior as examined in this paper. Yet, their model does not incorporate monetary policy.

2.3 Model

The model examined here is based on Gertler (1999). We add a sticky price mechanism with endogenous capital whose accumulation is subject to an investment adjustment cost. This type of the model has been referred to as the “canonical model” by Edge (2003). We have six agents in this model, namely firms, capital producers, financial intermediaries, households, a government, and the central bank. As

¹³Particularly, Doepke and Schneider (2006) analyze one time shock on inflation, not the systematic response of monetary policy to inflation.

explained above, we limit our analysis to the cases with perfect foresight to avoid aggregation issues stemming from heterogeneous agents.

2.3.1 Firms

Firms face a cost minimization problem via price setting subject to a Rotemberg (1982) – type adjustment cost.

Marginal Cost Marginal cost, where there exist two inputs, namely labor L and capital K , is computed as in Christiano et al. (2005). By denoting real wages by $\frac{W}{P}$ and real cost of capital by r^K , each firm j minimizes total costs:

$$\frac{W_t}{P_t} L_{j,t} + r_t^K K_{j,t}$$

subject to the standard Cobb–Douglas production technology with capital share being α ,

$$Y_{j,t} = [Z_t \exp(z_t) L_{j,t}]^{1-\alpha} K_{j,t}^\alpha, \quad (1)$$

where Y is output, Z is deterministic technology growth, and z is a temporary technology shock. The Lagrangian multiplier of this optimization problem is the real marginal cost φ . This is assumed to be symmetric across monopolistically competitive firms:

$$\varphi_t = \left[\frac{W_t}{(1-\alpha) Z_t \exp(z_t) P_t} \right]^{1-\alpha} \left(\frac{r_t^K}{\alpha} \right)^\alpha.$$

Similarly, real wages and the cost of capital are also defined as follows:

$$\frac{W_t}{P_t} = (1-\alpha) \varphi_t [Z_t \exp(z_t)]^{1-\alpha} L_{j,t}^{-\alpha} K_{j,t}^\alpha, \quad (2)$$

$$r_t^K = \alpha \varphi_t [Z_t \exp(z_t)]^{1-\alpha} L_{j,t}^{1-\alpha} K_{j,t}^{\alpha-1}. \quad (3)$$

Price Setting Under monopolistic competition and Rotemberg-type adjustment with a cost parameter ϕ and a target gross inflation rate of unity, each firm sets prices in order to maximize discounted sum of its period real dividends D :

$$D_{j,t} = (1 + \tau) \frac{P_{j,t}}{P_t} Y_{j,t} - \varphi_t Y_{j,t} - \frac{\phi}{2} \left(\frac{P_{j,t}}{P_{j,t-1}} - 1 \right)^2 Y_t, \quad (4)$$

subject to a downward sloping demand curve with elasticity of substitution κ :

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\kappa} Y_t.$$

τ denotes a production subsidy designed to eliminate the distortion stemming from monopolistic competition:

$$\tau = \frac{1}{\kappa - 1}.$$

In a symmetric equilibrium where $P_{j,t} = P_t$, the first order necessary condition implies

$$\kappa (\varphi_t - 1) - \phi (\pi_t - 1) \pi_t + \frac{m_{0,t+1}}{m_{0,t}} \phi (\pi_{t+1} - 1) \pi_{t+1} = 0, \quad (5)$$

where gross inflation rate is defined by

$$\pi_t = \frac{P_t}{P_{t-1}},$$

m denotes the pricing kernel used value profits over time. Formally, it is determined as the weighted marginal utilities of the share holders as shown in Heathcote and Perri (2004) and Carceles-Poveda and Coen-Pirani (2008):

$$m_{0,t} = \beta^t \left[w^w \frac{\partial V_t^w}{\partial C_t^w} + (1 - w^w) \frac{\partial V_t^r}{\partial C_t^r} \right],$$

where β is the subjective discount factor, w^w is the weight on the workers' marginal utility, which is, for example, assumed to be given by the relative share holdings

in Heathcote and Perri (2004), V and C denote recursive utility and consumption respectively. The superscript w describes a variable that applies to workers, while r stands for retirees. We do not face the usual complication in aggregation stemming from heterogeneous agents, since we limit our analysis to the case of perfect foresight.

2.3.2 Capital Producers

Capital producers, who maximize profits under a perfectly competitive market, enter the current period t with K_t units of capital. This is the amount of capital they can rent to final goods producers in the current period and receive a (nominal) factor payment of $P_t r_t^K K_t$. Furthermore, these capital-producing firms have borrowed from a financial intermediary in this period. The nominal value of these funds is A_t , since A_t is total nominal funds invested by the financial intermediary in period t . The firm pays a gross nominal interest rate R_t^K on these funds. The firm also undertakes new investment, $P_t I_t$, and borrows the amount A_{t+1} from the financial intermediary. The firms' period real profits Π_t^K are given by

$$\Pi_t^K = \frac{A_{t+1}}{P_t} + r_t^K K_t - I_t - R_t^K \frac{A_t}{P_t}. \quad (6)$$

Firms maximize the sum of profits valued using the pricing kernel displayed above, subject to the production technology of capital used by firms:

$$K_{t+1} = (1 - \delta) K_t + \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) \right] I_t, \quad (7)$$

where $S(\cdot)$ is the adjustment cost function used in Christiano et al. (2005):¹⁴

$$S\left(\frac{I_t}{I_{t-1}}\right) = [(1+z)(1+n)]^2 S'' \left[\frac{\left(\frac{I_t}{I_{t-1}}\right)^2}{2[(1+z)(1+n)]^2} - \frac{I_t}{I_{t-1}(1+z)(1+n)} + \frac{1}{2} \right],$$

where S'' determines the size of this adjustment cost, and is the second derivative of this adjustment cost function with respect to I_t/I_{t-1} . From first order necessary conditions, we can obtain the equation for rental cost of capital:

$$Q_t = \frac{\pi_{t+1}}{R_{t+1}^K} [Q_{t+1}(1-\delta) + r_{t+1}^K], \quad (8)$$

where Q is the Lagrange multiplier on the capital formation, whose dynamics are expressed as

$$Q_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right) \frac{I_t}{I_{t-1}} \right] + \frac{\pi_{t+1}}{R_{t+1}^K} Q_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right) \left(\frac{I_{t+1}}{I_t}\right)^2 = 1. \quad (9)$$

Here we have used the definition of the pricing kernel obtained from optimal condition as

$$\frac{m_{0,t+1}}{m_{0,t}} = \frac{\pi_{t+1}}{R_{t+1}^K}. \quad (10)$$

2.3.3 Financial Intermediaries

Our model also includes financial intermediaries that lend funds to the capital producers and holds equity of the final goods producers and the capital producers. Households can put their money into this financial intermediary and receive a return

¹⁴As shown in Dupor (2001), Carlstrom and Fuerst (2005) and Woodford (2003), realistic empirical properties of this sort of the model, especially in responses to a policy shock, are only obtained with an investment adjustment cost.

that is composed of the returns on equities and the funds that are given to the capital producers. Financial intermediaries maximize their real profits:

$$\begin{aligned}\Pi_t^{FI} &= R_t^K \frac{A_t}{P_t} + \left(\bar{P}_t^F + D_t\right) x_t^F + \left(\bar{P}_t^K + \Pi_t^K\right) x_t^K \\ &\quad - \bar{P}_t^F x_{t+1}^F - \bar{P}_t^K x_{t+1}^K - \frac{A_{t+1}}{P_t} + \frac{\left(F A_{t+1}^w + F A_{t+1}^r\right)}{P_t} - R_t \frac{F A_t^w + F A_t^r}{P_t},\end{aligned}$$

where x is the share of the equity, and \bar{P} is the price of such assets, where superscript F denotes those of final goods firms while K denotes those of capital producers. From the first order necessary conditions, we obtain the arbitrage conditions:¹⁵

$$\frac{m_{0,t}}{m_{0,t+1}} = \frac{\bar{P}_{t+1}^F + D_{t+1}}{E_t^F}, \quad (11)$$

$$\frac{m_{0,t}}{m_{0,t+1}} = \frac{\bar{P}_{t+1}^K + \Pi_{t+1}^K}{E_t^K}, \quad (12)$$

$$\frac{m_{0,t}}{m_{0,t+1}} = \frac{R_{t+1}^K}{\pi_{t+1}},$$

and

$$\frac{m_{0,t}}{m_{0,t+1}} = \frac{R_{t+1}}{\pi_{t+1}}, \quad (13)$$

where we define E as the real amount of equity holdings.¹⁶ Since we only conduct perfect foresight simulations in this paper, all assets produce the same rate of return.

Therefore, portfolio choice is irrelevant as is obvious from the condition below:

$$\frac{\bar{P}_{t+1}^F + D_{t+1}}{P_t^F} = \frac{\bar{P}_{t+1}^K + \Pi_{t+1}^K}{P_t^K} = \frac{R_{t+1}^K}{\pi_{t+1}} = \frac{R_{t+1}}{\pi_{t+1}}.$$

¹⁵Since these arbitrage conditions hold only in the absence of the unexpected shocks, these do not apply on the initial date when the shock hits the economy. Therefore, we distribute the initial profits from financial intermediaries between different agents according to their amounts of financial assets holdings in period zero, namely in the stationary population.

¹⁶This equals to the relative price of equities since the share is unity in aggregate.

2.3.4 Government

The government simply collects a lump-sum tax to subsidize firms in order to eliminate the distortion caused by monopolistic competition. We assume that each agent faces the same level of the lump sum tax T . Therefore, the budget constraint which the government faces is simply

$$\tau Y_t = (N_t + N_t^r) T_t, \quad (14)$$

where N denotes the population of workers while N^r is that of retirees.

2.3.5 Households

In the life-cycle economy assumed in this model, there are two types of households: retirees and workers.

Retiree Retirees, denoted by superscript r , who were born at j and become retired at k , are assumed to maximize their recursive utility¹⁷ from consumption and leisure $1 - L$:¹⁸

$$V_t^{rjk} = \left\{ \left[\left(C_t^{rjk} \right)^{\nu} \left(1 - L_t^{rjk} \right)^{1-\nu} \right]^{\rho} + \beta \gamma \left(V_{t+1}^{rjk} \right)^{\rho} \right\}^{\frac{1}{\rho}},$$

where ρ determines the intertemporal elasticity of substitution and ν defines the marginal rate of transformation between consumption and leisure. Since rate of survival of retirees, specifically his probability of surviving until the next period, is assumed to be γ , future welfare is discounted by common subjective discount factor

¹⁷The functional form is quite similar to the one in Lucas and Stokey (1984), and Epstein and Zin (1991).

¹⁸A Cobb-Douglas utility function satisfies the balanced growth restriction.

multiplied with γ . This optimization problem is subject to their intertemporal budget constraint:

$$\frac{FA_{t+1}^{rjk}}{P_t} = \left(\frac{R_t}{\gamma}\right) \frac{FA_t^{rjk}}{P_t} + \frac{W_t}{P_t} \xi L_t^{rjk} - C_t^{rjk} - T_t,$$

where FA is the amount of their financial asset holding and $\xi \in [0, 1]$ is the relative marginal product of labor of the retirees to that of workers. It is natural to assume that retirees receive less compensation than workers.¹⁹ The real rate of return is now $\frac{R_t}{\gamma}$ since bequests are distributed among retirees by the life insurance company in a perfectly competitive market.²⁰ From the first order necessary conditions, we can derive the relationship between consumption and labor supply:

$$L_t^{rjk} = 1 - \frac{1-v}{v} \frac{P_t}{\xi W_t} C_t^{rjk},$$

and the consumption Euler equation:

$$C_{t+1}^{rjk} = \left[\beta R_{t+1} \left(\frac{1}{\pi_{t+1}}\right)^{1-\rho+v\rho} \left(\frac{W_t}{W_{t+1}}\right)^{(1-v)\rho} \right]^{\frac{1}{1-\rho}} C_t^{rjk}. \quad (15)$$

From these equations, we derive the consumption function, in the form of total wealth multiplied by the marginal propensity to consume out of wealth $\epsilon\theta$:

$$C_t^{rjk} = \epsilon_t \theta_t \left[\left(\frac{R_t}{\gamma}\right) \frac{A_t^{rjk}}{P_t} + H_t^{rjk} + PT_t^{rjk} \right]. \quad (16)$$

¹⁹There are other interpretations for ξ . It can be considered to reflect the incentive and legal structure, pension system, the relative labor income tax rate, or the custom taken by firms to reduce the total personnel expenses.

²⁰In this paper, insurance is perfect within generations, but transitional risk from a worker to a retiree is uninsurable. For details, see Blanchard (1985) and Yaari (1965).

By iterating the budget constraint forward, human wealth H can be expressed in a recursive manner:

$$H_t^{rjk} = \frac{W_t}{P_t} \xi L_t^{rjk} + \frac{\gamma \pi_{t+1}}{R_{t+1}} H_{t+1}^{rjk}.$$

Similarly, the present discounted value of lump sum taxes PT , is expressed as

$$PT_t^{rjk} = -T_t + \frac{\gamma \pi_{t+1}}{R_{t+1}} PT_{t+1}^{rjk}$$

We can then derive the dynamic equation for the marginal propensity to consume

$$\epsilon_t \theta_t = 1 - \frac{\epsilon_t \theta_t}{\epsilon_{t+1} \theta_{t+1}} \gamma R_{t+1}^{\frac{\rho}{1-\rho}} \beta^{\frac{1}{1-\rho}} \left(\frac{1}{\pi_{t+1}} \right)^{\frac{v\rho}{1-\rho}} \left(\frac{W_t}{W_{t+1}} \right)^{\frac{(1-v)\rho}{1-\rho}}. \quad (17)$$

Furthermore, we can find a value function that satisfies the above conditions:

$$V_t^{rjk} = (\epsilon_t \theta_t)^{-\frac{1}{\rho}} C_t^{rjk} \left(\frac{1-v}{v} \frac{P_t}{\xi W_t} \right)^{1-v}. \quad (18)$$

Workers Workers, denoted by superscript w , who were born at j , maximize their recursive utility:

$$V_t^{wj} = \left\{ \left[(C_t^{wj})^v (1 - L_t^{wj})^{1-v} \right]^\rho + \beta [\omega V_{t+1}^{wj} + (1 - \omega) (V_{t+1}^{rj})]^\rho \right\}^{\frac{1}{\rho}}$$

subject to

$$\frac{FA_{t+1}^{wj}}{P_t} = R_t \frac{FA_t^{wj}}{P_t} + \frac{W_t}{P_t} L_t^{wj} - C_t^{wj} - T_t,$$

where ω is the probability that the current worker will remain a worker in the next period. From the first order necessary conditions, we can derive the relationship between consumption and labor supply:

$$L_t^{wj} = 1 - \frac{1-v}{v} \frac{P_t}{W_t} C_t^{wj}.$$

and the consumption Euler equation:

$$\begin{aligned}
& \left[(C_t^{wj})^v (1 - L_t^{wj})^{1-v} \right]^{\rho-1} (1 - L_t^{wj})^{1-v} v (C_t^{wj})^{v-1} \\
&= \beta \left[\omega V_{t+1}^{wj} + (1 - \omega) (V_{t+1}^{rj}) \right]^{\rho-1} \\
& \quad v \frac{R_{t+1}}{P_{t+1}} \left(\begin{array}{c} \omega P_t (V_{t+1}^{wj})^{1-\rho} (C_{t+1}^{wj})^{v\rho-1} (1 - L_{t+1}^{wj})^{(1-v)\rho} \\ + (1 - \omega) P_t (V_{t+1}^{rj})^{1-\rho} (C_{t+1}^{rj})^{v\rho-1} (1 - L_{t+1}^{rj})^{(1-v)\rho} \end{array} \right).
\end{aligned}$$

Then, we guess that the value function takes the form:

$$V_t^{wj} = (\theta_t)^{-\frac{1}{\rho}} C_t^{wj} \left(\frac{1-v}{v} \frac{P_t}{W_t} \right)^{1-v}, \quad (19)$$

where θ is the marginal propensity to consume for workers. This leads to the Euler condition:

$$\begin{aligned}
& \omega C_{t+1}^{wj} + (1 - \omega) (\epsilon_{t+1})^{-\frac{1}{\rho}} C_{t+1}^{rj(t+1)} \left(\frac{1}{\xi} \right)^{1-v} \\
&= \left[\beta \frac{R_{t+1}}{\pi_{t+1}} \left(\omega + (1 - \omega) (\epsilon_{t+1})^{-\frac{1-\rho}{\rho}} \left(\frac{1}{\xi} \right)^{1-v} \right) \left(\frac{W_{t+1}}{W_t \pi_{t+1}} \right)^{(v-1)\rho} \right]^{\frac{1}{1-\rho}} C_t^{wj}.
\end{aligned} \quad (20)$$

As with the case for retirees, we are looking to identify the marginal propensity to consume out of wealth in the consumption demand:

$$C_t^{wj} = \theta_t \left(R_t \frac{A_t^{wj}}{P_t} + H_t^{wj} + P T_t^{wj} \right). \quad (21)$$

By using the consumption Euler equation and the consumption function, we can derive a dynamic equation as follows:

$$\begin{aligned}
& \left\{ 1 - \beta^{\frac{1}{1-\rho}} \left(\frac{P_t R_{t+1}}{P_{t+1}} \Omega_{t+1} \right)^{\frac{\rho}{1-\rho}} \left(\frac{P_t}{P_{t+1}} \frac{W_{t+1}}{W_t} \right)^{\frac{(v-1)\rho}{1-\rho}} \frac{\theta_t}{\theta_{t+1}} - \theta_t \right\} R_t \frac{A_t^{wj}}{P_t} \\
&= \left\{ -1 + \theta_t + \beta^{\frac{1}{1-\rho}} \left(\frac{P_t R_{t+1}}{P_{t+1}} \Omega_{t+1} \right)^{\frac{\rho}{1-\rho}} \left(\frac{P_t}{P_{t+1}} \frac{W_{t+1}}{W_t} \right)^{\frac{(v-1)\rho}{1-\rho}} \frac{\theta_t}{\theta_{t+1}} \right\} H_t^{wj} \\
& \quad (H_t^{wj} + F_t^{wj}) - \left(\frac{W_t}{P_t} L_t^{wj} + D_t^{wj} \right) - \frac{P_{t+1}}{P_t R_{t+1}} \frac{\omega}{\Omega_{t+1}} H_{t+1}^{wj} \\
& \quad - \frac{P_{t+1}}{P_t R_{t+1}} \frac{1}{\Omega_{t+1}} (1 - \omega) (\epsilon_{t+1})^{-\frac{1}{\rho}} \left(\frac{1}{\xi} \right)^{1-v} \epsilon_{t+1} H_{t+1}^{rj},
\end{aligned}$$

where we define

$$\Omega_{t+1} = \omega + (1 - \omega) (\epsilon_{t+1})^{-\frac{1-\rho}{\rho}} \left(\frac{1}{\xi} \right)^{1-v}. \quad (22)$$

This equation holds if

$$\begin{aligned} \theta_t &= 1 - \beta^{\frac{1}{1-\rho}} \left(\frac{1}{\pi_{t+1}} \right)^{\frac{\rho v}{1-\rho}} (R_{t+1})^{\frac{\rho}{1-\rho}} \Omega_{t+1}^{\frac{\rho}{1-\rho}} \left(\frac{W_{t+1}}{W_t} \right)^{\frac{(v-1)\rho}{1-\rho}} \frac{\theta_t}{\theta_{t+1}}, \quad (23) \\ H_t^{wj} &= \frac{W_t}{P_t} L_t^{wj} + \omega \frac{P_{t+1}}{P_t} \frac{H_{t+1}^{wj}}{R_{t+1} \Omega_{t+1}} + (1 - \omega) (\epsilon_{t+1})^{\frac{\rho-1}{\rho}} \left(\frac{1}{\xi} \right)^{1-v} \frac{P_{t+1}}{P_t} \frac{H_{t+1}^{rj}}{R_{t+1} \Omega_{t+1}}, \end{aligned}$$

and

$$PT_t^{wj} = -T_t + \omega \frac{P_{t+1}}{P_t} \frac{PT_{t+1}^{wj}}{R_{t+1} \Omega_{t+1}} + (1 - \omega) (\epsilon_{t+1})^{\frac{\rho-1}{\rho}} \left(\frac{1}{\xi} \right)^{1-v} \frac{P_{t+1}}{P_t} \frac{PT_{t+1}^{rj}}{R_{t+1} \Omega_{t+1}},$$

If these equations are satisfied, the surmised value function has a solution.

No Life-Cycle Benchmark As a test-case for our model, we first examine the case where $\omega = 1$. With this assumption, workers live forever, and so we delete the life-cycle aspects of the model. Since this assumption does not affect the behavior in other sectors, we show just the households' choice problem. The equilibrium condition for households are obtained by maximizing the recursive utility as below:

$$V_t = \left\{ [(C_t)^v (1 - L_t)^{1-v}]^\rho + \beta (V_{t+1})^\rho \right\}^{\frac{1}{\rho}},$$

subject to the standard budget constraint:

$$\frac{FA_{t+1}}{P_t} = R_t \frac{FA_t}{P_t} + \frac{W_t}{P_t} L_t - C_t - T_t.$$

2.3.6 Monetary Policy

Monetary policy follows a standard Taylor type instrument rule as in Taylor (1993):

$$R_{t+1} = R_{SS} + 1.5\pi_t + \frac{0.5}{4} \left(\frac{Y_t}{Y_t^F} - 1 \right) + e_t, \quad (24)$$

where R_{SS} is the short-term nominal interest rate in stationary population, Y^F is the output in the flexible price equilibrium, computed simultaneously by assuming the absence of nominal rigidities. Since all variables are in quarterly terms, the coefficient on the output gap is divided by four. As is obvious from the setting of a Rotemberg-type adjustment cost and this equation, the target level of inflation is set to zero.

2.3.7 Aggregation

In this subsection, we first summarize the population growth in this model. Then, we transform equations that define individual behavior into aggregate form.

Population Growth The dynamics of the population of workers are expressed as follows:

$$\begin{aligned} N_{t+1} &= (1 - \omega + n) N_t + \omega N_t \\ &= (1 + n) N_t, \end{aligned}$$

where n is the growth rate of workers, while that of retirees is

$$N_{t+1}^r = (1 - \omega) N_t + \gamma N_t^r.$$

Hence, assuming a stationary population, the ratio of the number of retirees to that of workers remains constant:

$$\frac{N^r}{N} = \frac{1 - \omega}{1 + n - \gamma} = \Gamma, \quad (25)$$

which means that both the working and retired populations grow at the same rate n .

Aggregation If we assume the existence of a non-profit life insurance company that distributes wealth among retirees, the marginal propensity to consume is equated across all retirees. Therefore, subscripts j and k in most equations above can be removed. Below, we show the aggregate equilibrium conditions. The law of motion of assets held by retirees in aggregate is defined by

$$\begin{aligned} \frac{FA_{t+1}^r}{P_t} &= R_t \frac{FA_t^r}{P_t} + \frac{W_t}{P_t} \xi L_t^r - C_t^r - \frac{\Gamma}{1+\Gamma} \tau Y_t \\ &+ (1-\omega) \left(R_t \frac{FA_t^w}{P_t} + \frac{W_t}{P_t} L_t^w - C_t^w - \frac{1}{1+\Gamma} \tau Y_t \right), \end{aligned} \quad (26)$$

where we express the expenses stemming from the lump sum tax by using equations (14) and (25). Next, we aggregate individual labor supply. This simply involves multiplying by the population of each category:

$$L_t^r = \Gamma N_t - \frac{1-v}{v} \frac{P_t}{\xi W_t} C_t^r, \quad (27)$$

and

$$L_t^w = N_t - \frac{1-v}{v} \frac{P_t}{W_t} C_t^w. \quad (28)$$

Furthermore, because the population growth rate in each category is $(1+n)$, the discount rate when computing financial and human wealth also changes. Therefore,

$$H_t^r = \frac{W_t}{P_t} \xi L_t^r + \frac{\gamma \pi_{t+1}}{(1+n) R_{t+1}} H_{t+1}^r, \quad (29)$$

$$H_t^w = \frac{W_t}{P_t} L_t^w + \omega \frac{H_{t+1}^w \pi_{t+1}}{(1+n) R_{t+1} \Omega_{t+1}} + (1-\omega) (\epsilon_{t+1})^{\frac{\rho-1}{\rho}} \left(\frac{1}{\xi} \right)^{1-v} \frac{H_{t+1}^r \pi_{t+1}}{(1+n) R_{t+1} \Omega_{t+1}}. \quad (30)$$

Similarly, we can rewrite the present discounted values for the lump sum tax:

$$PT_t^r = -\frac{\Gamma}{1+\Gamma} \frac{1}{\kappa-1} Y_t + \frac{\gamma \pi_{t+1}}{(1+n) R_{t+1}} PT_{t+1}^r, \quad (31)$$

and

$$PT_t^w = -\frac{1}{1+\Gamma} \frac{1}{\kappa-1} Y_t + \omega \frac{PT_{t+1}^w \pi_{t+1}}{(1+n)R_{t+1}\Omega_{t+1}} + (1-\omega) (\epsilon_{t+1})^{\frac{\rho-1}{\rho}} \left(\frac{1}{\xi}\right)^{1-\nu} \frac{PT_{t+1}^r \pi_{t+1}}{(1+n)R_{t+1}\Omega_{t+1}}. \quad (32)$$

Market Clearing Finally, applying the market clearing conditions, the financial market equilibrium is

$$\frac{FA_{t+1}^w + FA_{t+1}^r}{P_t} = E_{t+1}^F + E_{t+1}^K + \frac{A_{t+1}}{P_t}. \quad (33)$$

The labor market clearing condition is

$$L_t = L_t^w + \xi L_t^r, \quad (34)$$

and the goods market clearing condition, namely the resource constraint, is expressed as

$$Y_t = C_t^r + C_t^w + I_t. \quad (35)$$

System of Equations The system of equations consists of structural equations:²¹ (1), (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), (16), (17), (18), (19), (21), (22), (23), (24), (26), (27), (28), (29), (30), (31), (32), (33), (34), (35), and their counterparts in a flexible equilibrium, that are computed by excluding nominal rigidity and therefore equation (24). Since we assume both deterministic technology and population growth, endogenous variables are de-trended: $C, D, F, H, I, K, PT, Y, \Pi^K$ are de-trended by ZN ; A and FA is de-trended by ZNP ; W is de-trended by ZP ; L is de-trended by N ; and V is by $Z^v N$.

²¹Some are derived before assuming the symmetry of agents and aggregation.

2.4 Properties under Stationary Population

Parameters in the baseline life-cycle economy are depicted in Table 1. Since the model is solved with quarterly frequency, parameters are on quarterly terms. In our baseline life-cycle economy, we assume that people work from age 21 to 65, which is defined by ω , while people remain in retirement from age 66 to 75, defined by γ , based on Auerbach and Kotlikoff (1987). Other parameters which define life-cycle behavior are exactly the same as those in Gertler (1999) except for newly added parameters, namely θ , ϕ , and S'' . Elasticity of substitution among goods θ is set at the conventional value as calibrated in Smets and Wouters (2003), or Levin, Onatski, Williams and Williams (2005). The size of the Rotemberg-type adjustment cost ϕ is also set at the conventional value so that on average one-fourth of firms change prices in each period in a linearly observational equivalent specification *a la* Calvo (1983).²² The size of investment adjustment cost, S'' is taken from the estimated value in Christiano et al. (2005).

2.4.1 Values under Stationary Population

In this subsection, we study the long-run effects of different demographic structures. For this purpose, three versions of a stationary population are computed: (i) the baseline life-cycle economy is a younger economy (low γ), (ii) an older economy (high γ), and (iii) no life-cycle economy. Concerning demographic differences, individuals' life

²²Although this value has been thought to be conventional since the seminal research by Bils and Klenow (2004), recent studies, such as Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008), imply slightly shorter implied durations as three quarters.

Table 1: Parameter values

Parameter	Value	Description and Definitions
θ	5	$\theta / (\theta - 1)$ is markup
σ	.25	Intertemporal elasticity of substitution
ϕ	60	Price adjustment cost
β	$1.04^{-.25}$	Subjective discount factor
ω	$1.023^{-.25}$	Probability of remaining as worker
α	0.667	Labor share
δ	$1.1^{2.5} - 1$	Capital depreciation rate
ρ	-3	$(\sigma - 1) / \sigma$
ν	.4	Utility weight on consumption
ξ	.6	Labor productivity of retirees
γ	$1.1^{-.25}$	Probability of remaining as retirees
S''	2.48	Second derivative of adjustment cost
Z	$1.01^{0.25} - 1$	Technology growth rate
n	$1.01^{0.25} - 1$	Population growth rate
Γ	0.21	Stationary population ratio of retirees over workers
ρ_z	0.8	Technology shock persistence

Table 2: Values under stationary population

	c/y	k/y	R	a^r/k	θ	$\epsilon\theta$	l^w	l^r
(i)	.70	10.3	.01	.16	.017	.03	.41	.05
(ii)	.70	10.3	.01	.22	.014	.02	.41	.12
(iii)	.76	8.2	.02	—	.013*	—	.37*	—

expectancy becomes longer in (ii) older economy. In this economy, individuals retire at the age of 65 but are supposed to live until 85. To achieve this, the parameter that determines the probability of remaining as retirees, γ , is altered from $1.1^{-.25}$ to $1.05^{-.25}$. As a result of this alteration, the ratio workers to retirees Γ changes from 0.21 to 0.39. In (iii) no life-cycle economy, all households are symmetric, since they live infinitely long. An interpretation of this setting is that households can completely insure their risk of transition from workers and retirees, and are so altruistic that they consider the welfare of their descendents in their utility functions. Table 2 shows the values of major endogenous variables in (i) younger economy, (ii) older economy and (iii) no life-cycle economy, where * shows the variables of the representative agent in (iii).

First, we contrast the results in a model with heterogenous agents in the incomplete market setup with homogenous agents in complete market. In the former, workers need to prepare for the future period in which they become retirees because their labor productivity is lower than that of workers. Their incentive to save tends to become higher in this economy. These movements should result in higher capital-

output ratio, and therefore, real interest rates should be lower in (ii) older economy so that we can derive the usual results of a life-cycle model, namely dynamic inefficiency due to too much saving.²³

As it turns out, comparing different life-cycle economies yields somewhat counter-intuitive results. With the same reasoning as above, it seems natural that the capital-output ratio is higher and real interest rates are lower in (ii) older economy than (i) younger economy. The results in Table 2, however, show the opposite albeit slightly. The capital output ratio is 10.2684 in (i) and 10.2677 in (ii) while real interest rates are 0.008478 in (i) and 0.008480 in (ii). Yet, this is not a puzzle at all, if we understand the labor supply of the retirees. The longer life expectancy in retirees has two different effects, namely an increase in worker's marginal disutility for further saving and the retiree's marginal disutility for further reduction in leisure. As explained above, workers try to save more to prepare for longer retirement period. On the other hand, retirees need to work more even though their labor productivity is lower to maintain an optimized level of consumption. If the former dominates, real interest rates fall even in the economy where retirees have longer life expectancy. In this example, the latter dominates the former. Labor supply of retirees rises so much that workers accumulate less capital in (ii). This result that younger people save less in a economy where retiree's life expectancy is longer does, however, not hold generally. Under some parameter settings, real interest rates indeed become lower in a greyer

²³Comparison of marginal propensity to consume and labor supply between life-cycle economies and no life-cycle economy is not trivial since we need to compute average marginal propensity to consume and labor supply of workers and retirees in life-cycle economies.

society, which is consistent with the conventional wisdom as the second point raised by Bean (2004) in introduction. Thus, it is of great importance for a central bank to take demographic structure into account, since the natural rate of interest should be quite different across different demographic settings. We will check the sensitivity of our results in long-run properties model in the next subsection. Concerning the marginal propensity to consume, those of both workers and retirees decrease in (ii) because life expectancy increases.

2.4.2 Long-Run Properties under Alternative Demographic Structure

We next explore how the above results change when we assume alternative demographic structures by altering fundamental structural parameters, γ , and ξ . Figure 1 shows how effects on retiree's labor supply and real interest rates change as γ is varied from $1.2^{-0.25}$ to $1.025^{-0.25}$. Accordingly, the horizontal axis shows the average retirement years. Furthermore, values in shaded region coincide with those in (i) younger economy. As explained in the above subsection, the labor supply of retirees increases, as life expectancy grows. The relationship between the worker's saving and life expectancy is, however, not monotonic. While the average length of retirement is below 10 years, real interest rates fall, as consistent with conventional views. On the other hand, the length becomes longer than 10 years, real interest rates rise due to much higher labor participation by retirees.

How does the relative labor productivity of retirees to workers change due to movements in the stationary population? To answer this question, we compute the stationary population for ξ being 0.4 to 1.0 as shown in Figure 2. As the labor pro-

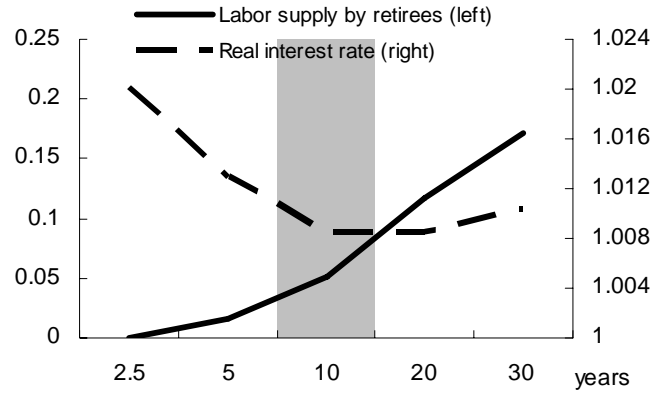


Figure 1: Long-run effects of average life expectancy

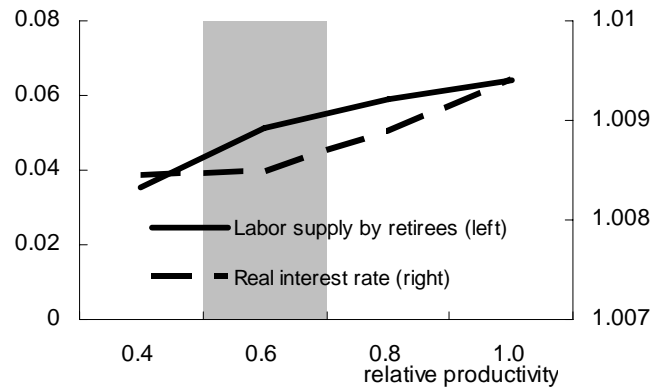


Figure 2: Long-run effects of labor productivity of retirees

ductivity becomes higher, retirees tend to work longer since they can receive more compensation per unit of labor supply. Furthermore, this implies that workers become less worried about becoming retirees and less productive. Hence, they consume more and save less. This results in higher real interest rates as the relative productivity of workers increases. Another intriguing result from this exercise is that retiree's labor supply is much lower than that of workers, even though there is no difference in labor productivity between workers and retirees, namely the economy is at the far right in the horizontal axis. In this situation, the only intrinsic difference between workers and retirees is the subjective discount factor. The fact that retirees have a lower subjective discount factor makes the marginal propensity to consume higher for retirees than for workers. Therefore, even if the labor productivity is the same across workers and retirees, retirees choose to consume more and to have additional leisure than increase labor supply.

We will check how above different demographic structures may alter the dynamic properties, namely the degree of amplification of impulse responses in the next section.

2.5 Dynamic Properties

In this section, we answer the two major questions raised in this paper, namely whether the structural shocks to the economy have asymmetric effects on workers and retirees and whether the considerations of life-cycle and demographic structure alter the dynamic properties of the solution. For this aim, we first analyze the im-

pulse responses to a level technology shock. Then, we investigate the transmission mechanism of a monetary policy shock. The reason why we choose these two shocks is that a technology shock can possibly have asymmetric effects on workers and retirees through the difference in labor productivity, while a positive shock on nominal interest rates may enhance the welfare of retirees since they rely more on financial assets.

2.5.1 Technology Shock

In this subsection, we study the impulse responses to a positive technology shock. First, we show impulse responses in (iii) no life-cycle economy as a benchmark.²⁴ Then, we compare these benchmark responses with those obtained in (i) younger economy and (ii) older economy. Finally, we demonstrate the shifts in impulse responses as the life expectancy of retirees becomes longer and their relative productivity becomes higher.

Benchmark: No Life-Cycle Economy The thick black lines in Figure 3 show the impulse responses to a shock to the level of technology in (iii) no life-cycle economy. A shock to the level of technology naturally increases the level of output, consumption and investment. Since the investment adjustment cost is embedded in the model, the response of investment is hump shaped. As the marginal cost becomes smaller due to the positive technology shock, the inflation rate and nominal interest

²⁴This is because the model in this paper differs from the standard model in utility specification. There have been very few researches on the new Keynesian model with a recursive utility.

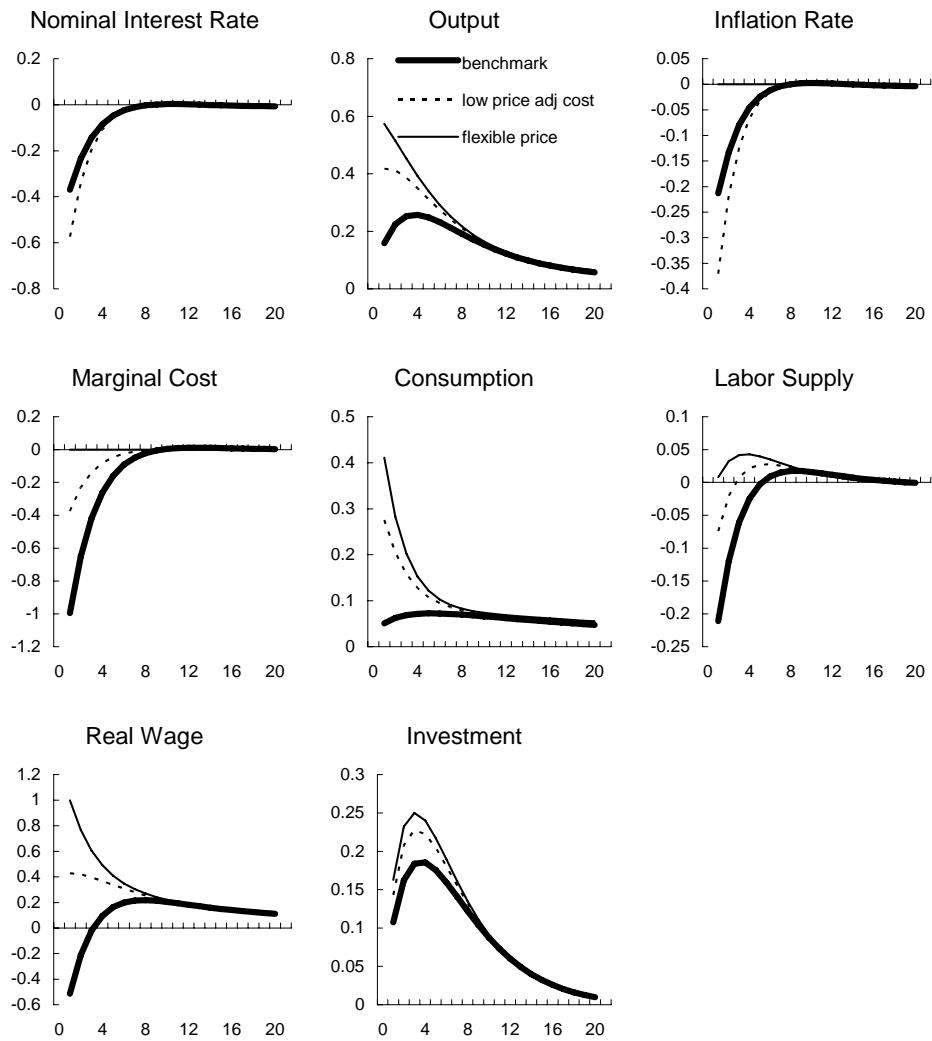


Figure 3: Responses to a technology shock in no life-cycle economy

rates are decreased.

Furthermore, as emphasized in Galí (1999) and Galí and Rabanal (2004), a shock to the level of technology reduces the labor supply due to the sticky price mechanism embedded in this model. Since monetary policy does not fully offset the distortion caused by varying the markup, the ability for a full increase in output reflecting the shock which expands the production frontier is limited. Therefore, a technology shock reduces labor supply in this model. The response of the real wage seems somewhat puzzling. The real wage decreases after a positive technology shock. This, however, is not puzzling at all. In a baseline case, after a level technology shock hits the economy, the existence of the Rotemberg-type price adjustment cost makes final goods' producers increase the markup and therefore, lower the marginal cost. The effect of the lowered marginal cost dominates the increase in technology itself. Therefore, as the labor demand curve shifts in, the real wage is reduced right after a shock hits the economy. Thin dotted lines show the responses when the Rotemberg-type price adjustment cost ϕ is reduced by one-fifth of that in the baseline case.²⁵ In this case, lowered price adjustment cost makes the markup less variable. Hence, a positive technology shock raises the real wage immediately. As consistent with theory, both labor supply and the real wage increase when the price is flexible as depicted by thin solid lines. Whether real wage decreases after the positive technology shock depends also on the investment adjustment cost. When monetary policy cannot fully accommodate shocks to technology, firms react by reducing their inputs mainly via labor demand since they face an investment adjustment cost. Thus, the leftward

²⁵As a result, 50% of firms can change prices in each period.

shift of the labor demand becomes more significant when the investment adjustment cost is higher.²⁶

Societal Aging Effects Here, we compare the responses in two life-cycle economies so that we can understand how the societal aging influences the time-properties of the economy. Then, we further investigate how shocks can have asymmetric effects on workers and retirees, respectively.

Figure 4 shows the responses to a technology shock in life-cycle economies. The thin lines demonstrate those in (i) younger economy and dotted lines show those in (ii) older economy. Overall, responses in life-cycle economies are similar to those obtained in the economy with homogeneous agents. There are, however, a few intriguing differences. First, a level technology shock has quite different effects on workers and retirees and hence, there could exist a welfare trade-off between workers and retirees when stabilizing the economy. Second, consumption in retirees shows much more of an increase in (ii) older economy. As a result, responses in (ii) older economy become more similar to those in (iii) no life-cycle economy.

On the first point, the responses of workers are both quantitatively and qualitatively quite different from those of retirees. For example, both responses of consumption and labor supply are much smaller especially in (i) younger economy, while consumption of workers increases right after a positive technology shock,²⁷ that of

²⁶This implies that introduction of habit persistence or labor adjustment cost will alter responses as shown in Vigfusson (2004). Furthermore, if sticky wage *a la* Erceg et al. (2000) is included, we will not see an immediate decrease in real wage.

²⁷Initial decrease is due to the decrease in labor supply and real wage that are explained in the

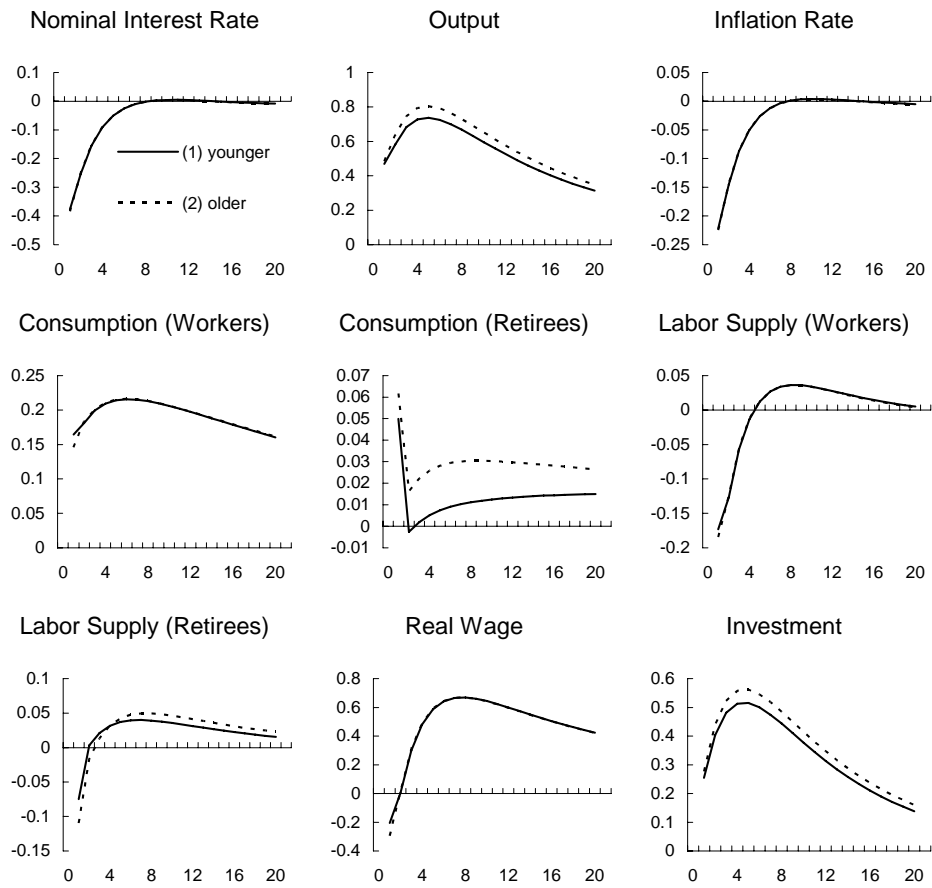


Figure 4: Responses to a technology shock in life-cycle economies

retirees is almost unchanged except for the initial period due to the theoretically consistent distribution of initial profits. Since retirees are less productive than workers, their labor supply is much smaller than those of workers, as shown in the previous section. Therefore, the gain from higher technology affects workers more than retirees.

Concerning the second point, comparing the responses between in (i) younger economy and in (ii) older economy leads us to notice that differences between workers and retirees become smaller in (ii) older life-cycle economy. As shown in previous section, in (i) older economy, retirees need to increase their labor supply to maintain optimal level of consumption. Thus, as life expectancy grows, retirees work more and therefore, retirees can enjoy the benefit of higher technology as much as workers can. Consequently, responses in (ii) older life-cycle economy becomes more similar to those in (iii) no life-cycle economy.

Sensitivity Analysis Here, we show how different demographic setups affect the responses to a technology shock.

Life Expectancy of Retirees Figure 5 shows the shifts in impulse responses to a level technology shock, as the life expectancy of retirees becomes longer. The thicker the line becomes, the longer the life expectancy of the retirees becomes. By “lines becoming thicker” we mean movements from the dashed line to the thin solid line and then to the thick solid line. There, 2.5y means that average life-expectancy

previous subsection.

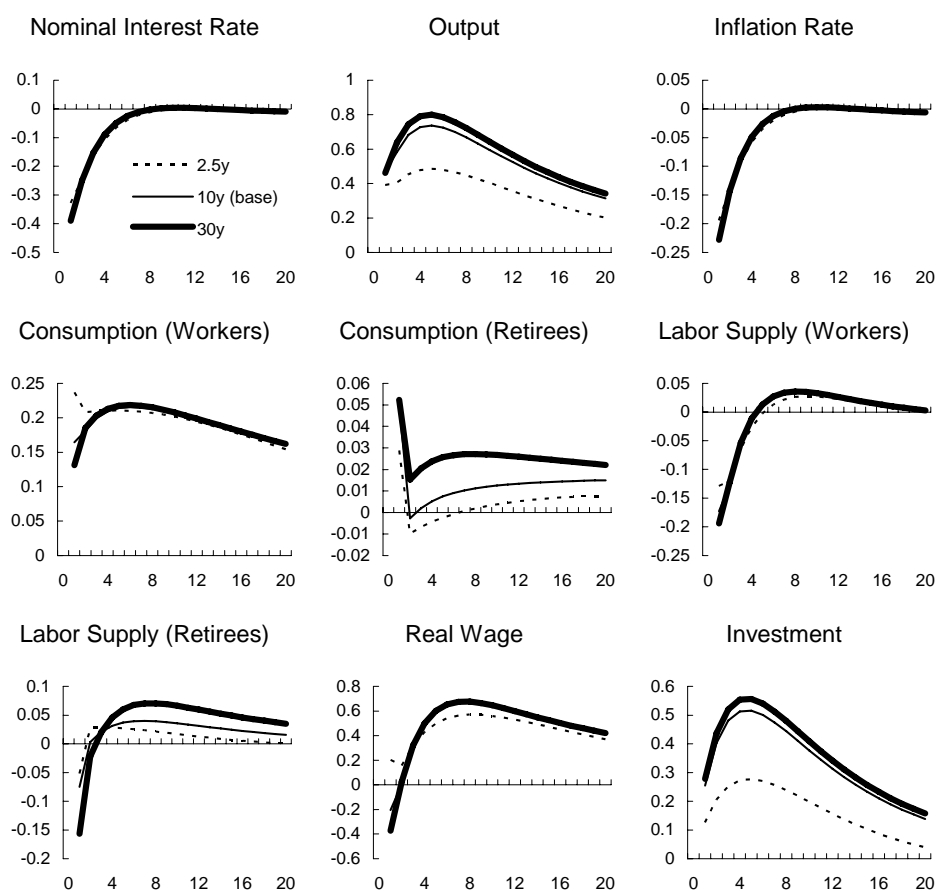


Figure 5: Responses to a technology shock as retiree's life expectancy becomes longer of retirees is 2.5 years. With shorter life expectancy, retirees rely more on income from returns on financial assets. Therefore, retirees do not alter consumption as well as leisure significantly. Reflecting these developments in retirees, workers can receive most of the benefits from higher technology. Since they do not have to prepare seriously for the life after retirement, they save (invest) less and therefore can enjoy huge welfare gain. On the other hand, the responses of aggregate output and the inflation rate become much larger as the retirees' labor supply in stationary population increase due to longer life expectancy as shown in Figure 1.

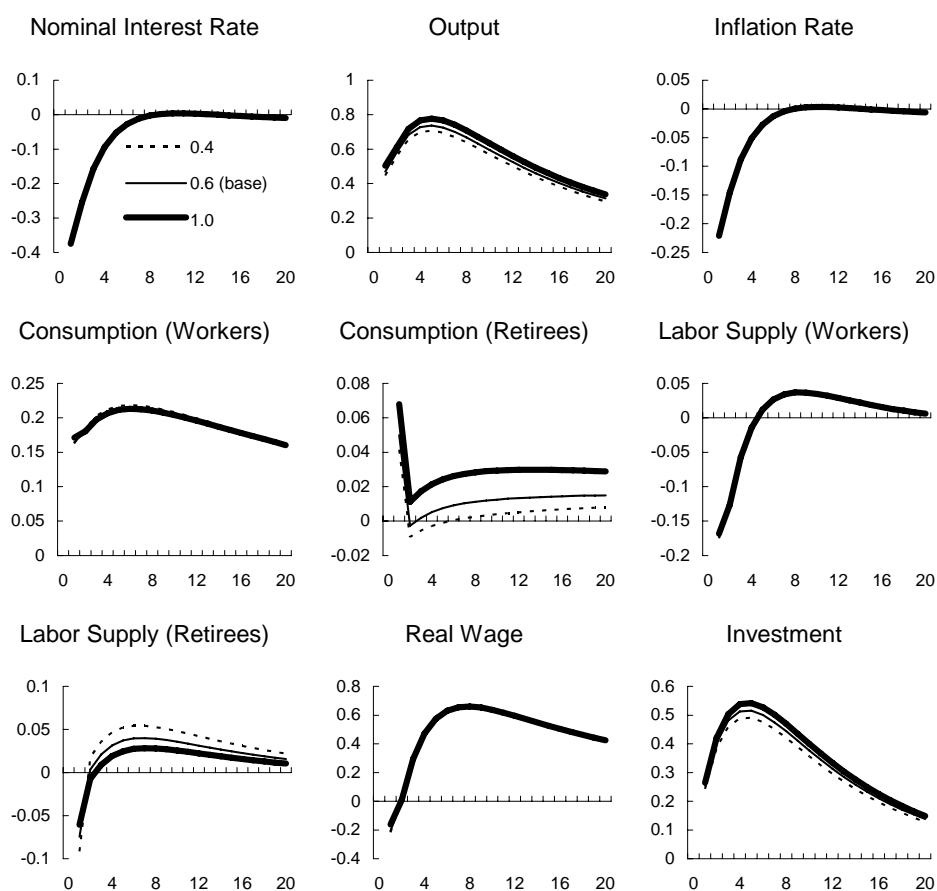


Figure 6: Responses to a technology shock as retiree's labor productivity becomes higher

Productivity of Retirees Figure 6 shows the responses as the relative labor productivity of retirees to workers changes. This time, the thicker the line becomes, the more productive the retirees become. Since there are no significant shifts in values in the stationary population as seen in Figure 2, different settings only result in minor differences for most variables. Yet, as the retirees become more productive, the difference between workers and retirees becomes smaller.

2.5.2 Monetary Policy Shock

In this subsection, we study the impulse responses to a monetary policy shock. First, we show the impulse responses in (iii) no life-cycle economy as a benchmark. Then, we compare this benchmark responses with those obtained in (i) younger economy and (ii) older economy. Finally, we demonstrate shifts in impulse responses as the life expectancy of retirees becomes longer and their relative productivity becomes higher.

Benchmark: No Life-Cycle Economy The impulse responses to a monetary policy shock in (iii) no life-cycle economy are shown in Figure 7. In this paper, we assume that the monetary policy shock is not serially correlated. A tightening shock reduces investment, consumption, and output via higher real interest rates. The decrease in output necessitates the reduction on inputs. Therefore, the real wage and eventually the marginal cost also fall. Consequently, we see a deflation after a positive shock to nominal interest rates.

Societal Aging Effects Figure 8 below compares the responses to a monetary policy shock in two life-cycle economies. As in Figure 4, the thin lines demonstrate those of (i) younger economy and dotted lines show those of (ii) older economy. Similarly to the case with a positive technology shock, responses of retirees are quite different from those of workers. Since retirees rely more on financial assets accumulated when they were workers, they mostly increase their consumption and leisure after a positive monetary tightening shock. In other words, income effects

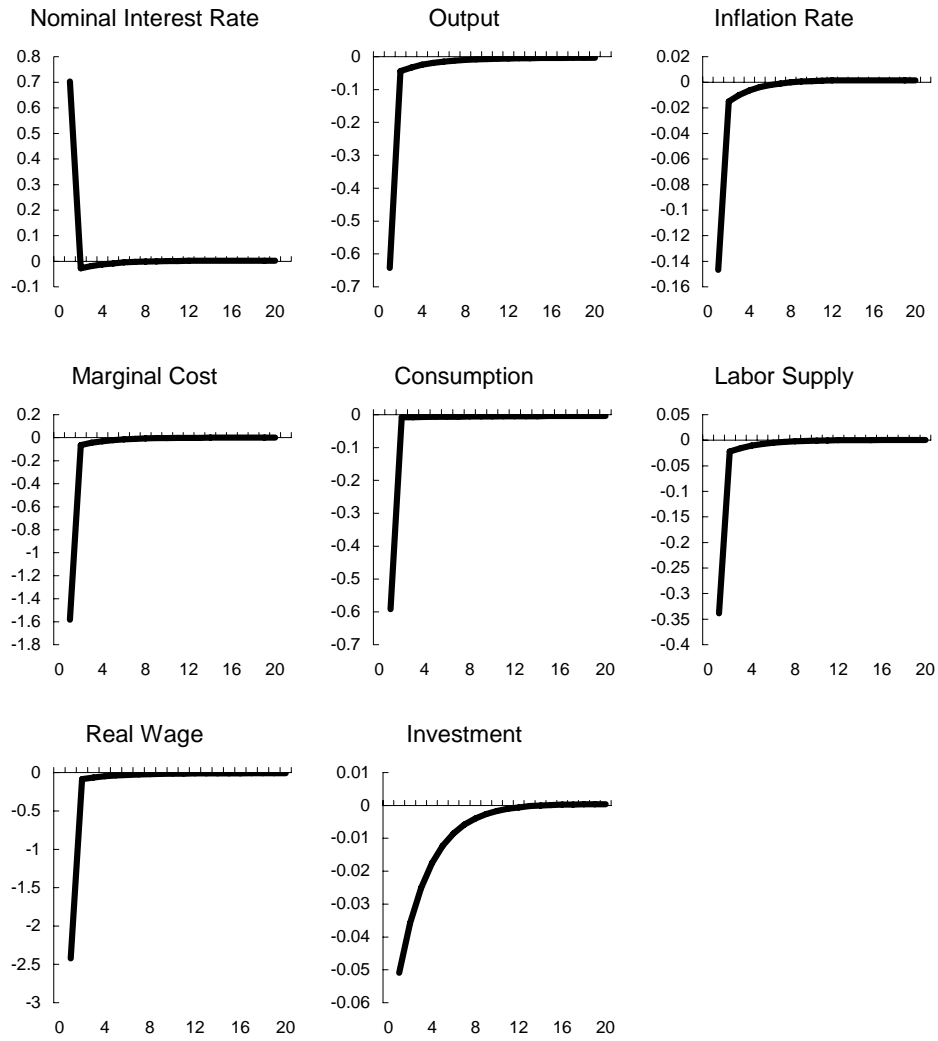


Figure 7: Responses to a monetary policy shock in no life-cycle economy

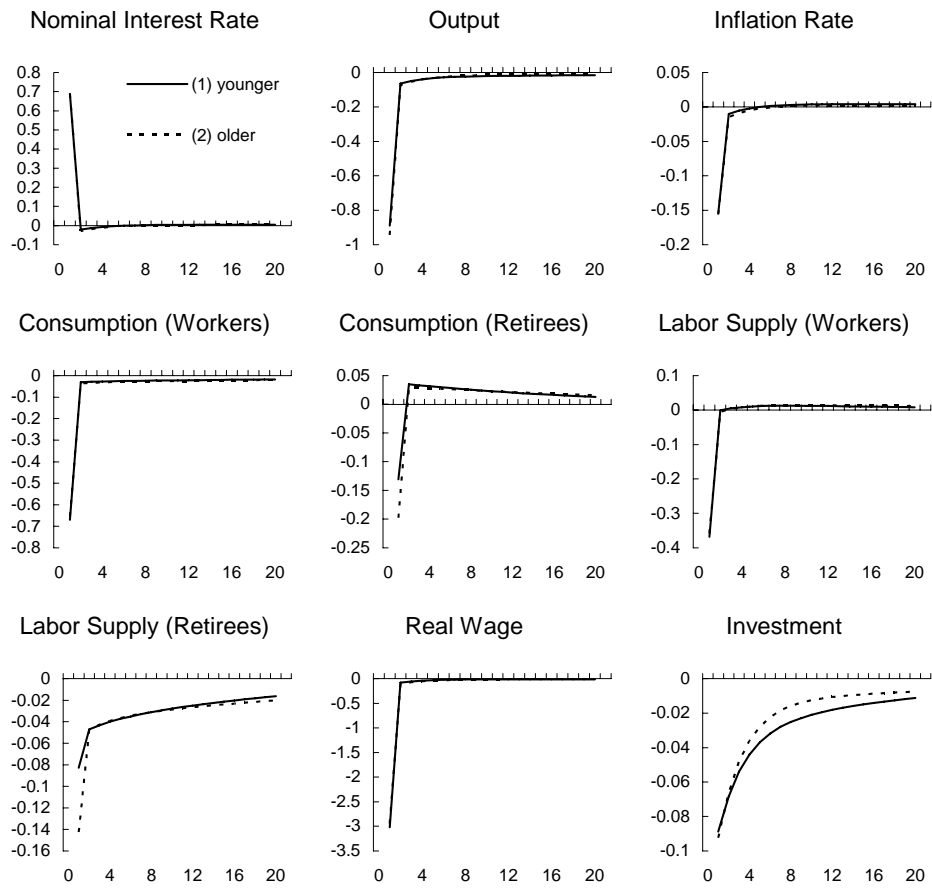


Figure 8: Responses to a monetary policy shock in life-cycle economies

from an increase in nominal interest rates dominate substitution effects for retirees. This implies that a central bank may face a severe policy trade-off: If the central bank cares more about retirees, or if monetary policy is determined mainly through opinions of older people because of their bargaining power in politics over younger people, there may be a bias towards higher nominal interest rates.²⁸

Again, in (ii) older economy, differences between workers and retirees become smaller. Due to higher labor supply to maintain optimal level of consumption by retirees, they become more similar to workers. As a result, a tightening monetary policy shock has much larger negative effects on the macroeconomy as a whole. Below, we will see how the effectiveness of a surprise in monetary policy can change as the demographic structure is altered.

Sensitivity Analysis We here demonstrate how the life expectancy and productivity of retirees may change the responses to a monetary policy shock.

Life Expectancy of Retirees Figure 10 demonstrates the responses to a monetary policy shock when the life expectancy of retirees becomes longer. As shown in Figure 1, labor supply of retirees is the smallest when the average life expectancy of retirees is only 2.5 years. In this case, since retirees hardly rely on their labor income but instead on the returns from financial assets, the consumption of retirees mostly increases while labor supply is even reduced. Yet, as societal aging deepens, although income effect becomes stronger for retirees, that of workers becomes weaker.

²⁸A stochastic welfare analysis is thus very interesting. The aggregation problem for the appropriate pricing kernel makes stochastic analysis not very trivial. This is left for our future research.

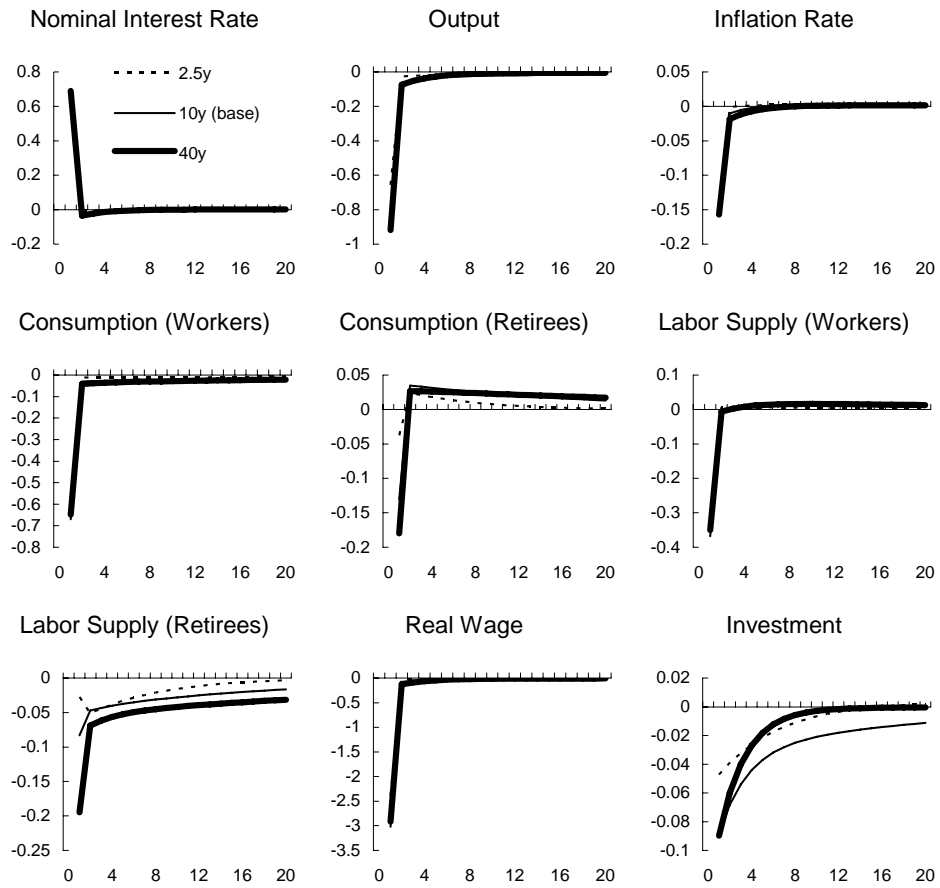


Figure 9: Responses to a monetary policy shock as retiree's life expectancy becomes longer

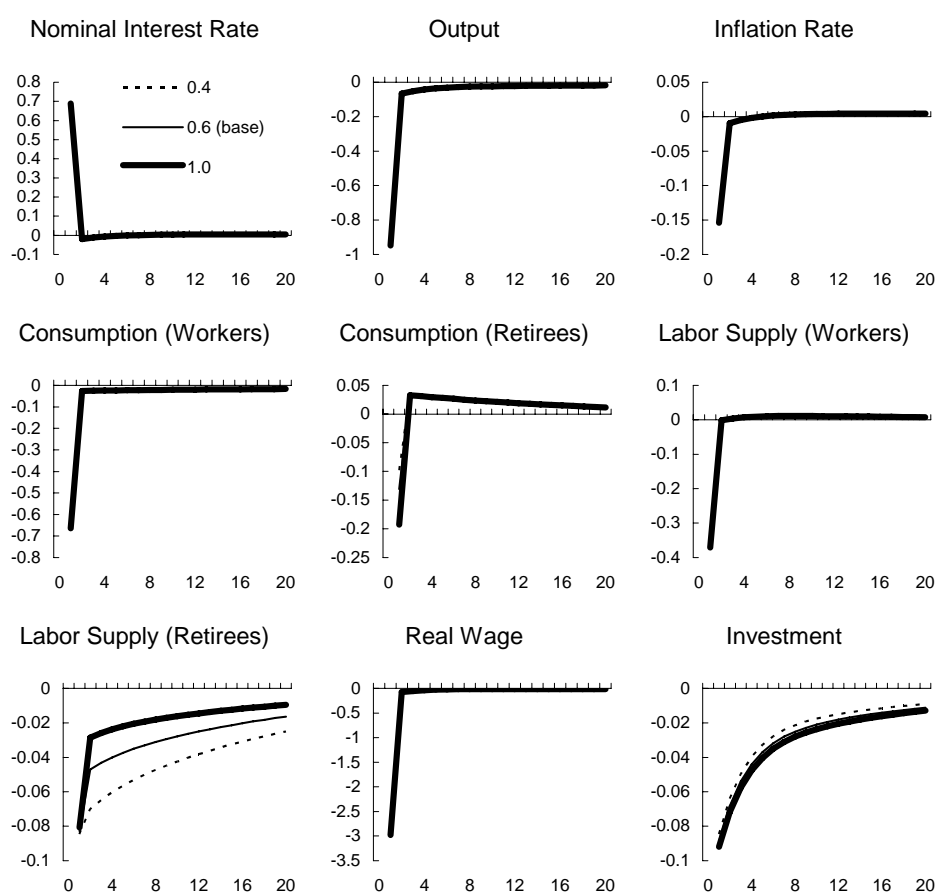


Figure 10: Responses to a monetary policy shock as retiree's labor productivity becomes higher

Hence, in aggregate, a tightening monetary policy shock still has negative impacts on the aggregate demand. Even though retiree's consumption increases, worker's consumption or the investment needs to be lowered since there is no expansion in the production frontier.

Productivity of Retirees Figure 9 below demonstrates the responses with changing labor productivity of retirees. With lower relative productivity of retirees, their labor supply in stationary population is very small as show in Figure 2. There-

fore, consumption of retirees mostly increases due to an increase in nominal interest rates. A positive shock on nominal interest rates increases the income from financial assets holdings for retirees, so they reduce labor supply. Therefore, retirees can enjoy leisure the most when their labor productivity is the lowest.

2.6 Conclusion

In this paper, we construct a dynamic new Keynesian life-cycle model based on Gertler (1999). Considering the fact that very little research has paid attention to monetary business cycle model or new Keynesian model with heterogeneous agents, the contribution of this paper is to analyze the effects of societal aging on the conducts of monetary policy. Findings in this chapter are summarized as follows.

We show that it is of great importance for a central bank to consider the demographics for sound monetary policy. First, the natural rate of interest differs as demographics change. Second, the structural shocks to the economy have asymmetric effects on heterogeneous agents, namely workers and retirees. Differences in the labor productivity between workers and retirees make a positive technology shock enhance the worker's but decrease the retiree's welfare. Furthermore, due to the higher reliance on financial assets, retirees become better off with a positive shock on nominal interest rates. This, especially, implies that a central bank may face a severe policy trade-off. If the central bank cares more about retirees, or if monetary policy is determined mainly through opinions of older people because of their bargaining power in politics over younger people, there may be a bias towards higher nominal

interest rates. Yet, even though societal aging deepens, in aggregate, a tightening monetary policy shock still has negative impacts on the aggregate demand since worker's consumption or the investment need to be lowered while consumption of retirees increase. Finally, the demographic structure changes the dynamic properties of the solution, namely the degree of amplification in the impulse responses. The less retirees work under stationary population, the less volatile macroeconomic variables are against shocks. Under such circumstances, a positive technology shock does not increase retiree's labor supply and so the negative effects from a positive monetary policy shock are alleviated by an increase in retiree's consumption.

In particular, the latter two points are very relevant to the recent economy developments in Japan, where the total population is expected to start decreasing and baby boomers are to retire *en masse* around 2007. Depending on whether retirees continue to work or not, macroeconomic responses to shocks could be dramatically changed in the foreseeable future. Not only could the effects unanticipated changes in monetary policy change but also a positive monetary policy shock may even temporarily increase output and inflation.

3 Re-thinking Price Stability in an Economy with Endogenous Firm Entry: Real Imperfections under Product Variety

3.1 Introduction

Reflecting growing interests in understanding the role of firm heterogeneity or endogenous variety in international trades as the seminal research by Melitz (2003) represents, macroeconomists also start considering consequences of incorporating firm dynamics into dynamic stochastic general equilibrium models. As noted in Bilbiie, Ghironi and Melitz (2007), the standard assumption in a widely used monetary business cycle model, as well summarized in Walsh (2003) and Woodford (2003), that monopolistically competitive firms can maintain positive profits without new entry should be considered unrealistic.²⁹

In this paper, we inquire into the price stability in an economy with such endogenous firm entry. Usually, studies using the new Keynesian model without considering the firm dynamics recommend central banks to completely stabilize the marginal cost and thus the inflation of producer prices. Furthermore, it is usually shown that the optimal inflation rate is zero, especially if the central bank can credibly commit to their policy.³⁰ Whether such a policy for aiming at price stability as above remain

²⁹Usually, it is assumed that firms continuously exist within the unit mass between 0 and 1.

³⁰With cost push shock, the central bank faces trade-offs. We will show some studies against price stability in next section. Furthermore, inflation bias arises when the central bank is discretionary.

valid even under product variety is an intriguing question. First, as Broda (2004) claims, “Measuring price changes accurately is central to the macroeconomic analysis used in conducting monetary policy. Various forms of bias in the consumer price index (CPI) have been documented in recent years, but a new form of bias tied to the introduction of new goods has only recently been explored empirically. Estimates of the ‘new goods’ bias suggest that CPI inflation has an upward bias of 0.3 percentage point.” That is, under endogenous firm entry, welfare-based CPI inflation becomes different from the inflation based on the producer prices. Thus, the central bank may be able to enhance social welfare by targeting the welfare-based price index, contrary to the case with the standard new Keynesian model without any product variety. Second, the optimal inflation rate may not be zero under firm dynamics. It still remains true that stabilizing marginal cost eliminates the inefficiency stemming from fluctuating markups, but, at the same time, non-zero inflation may increase the number of varieties, that produces higher utility, reflecting more profit opportunities. Therefore, a very interesting trade-off on price stability can exist when firm freely enter to and exit from the market. Yet, interestingly, Bilbiie, Ghironi and Melitz (2006, 2007) and Bergin and Corsetti (2005) show that even under endogenous firm entry, monetary policy that aims at marginal cost pricing, namely the cross-sectional average inflation targeting, remains desirable and the optimal inflation rate is zero.³¹

³¹Bergin and Corsetti (2005) and Bilbiie et al. (2007) call the producer price index (PPI) and consumer price index (CPI). Former corresponds to the cross-sectional average price index. and the latter is the welfare-based price index. As you will see, since the Rotemberg (1982) type of adjustment cost is employed, there is no cross dispersion of prices. However, I feel the naming of

The contribution of this paper is in examining whether keeping the cross sectional average inflation at zero still remains optimal under more general settings than in Bilbiie, Ghironi and Melitz (2006, 2007) and Bergin and Corsetti (2005), and obtain new policy prescriptions which is quite different from those in the past studies. We suppose a situation with imperfect knowledge on the natural rate of interest and under the distorted steady state. The reasons why these two new features can yield different policy prescription are as follows.

Why is the prescription obtained with the standard new Keynesian model still valid even under endogenous firm entry? First, it may come from the assumption of central banks' knowledge on the natural rate of interest, namely the Vicksellian interest rate. The actual implementation of monetary policy usually relies on some instrument rules. Hence, accurate knowledge of the natural rate of interest is necessary for the conduct of optimal monetary policy. The natural rate of interest is determined by the growth rate of the real marginal utility out of consumption, that is denominated by the welfare-based price index. Therefore, if the natural rate of interest is assumed to be perfectly known even under endogenous firm entry as in Bergin and Corsetti (2005) and Bilbiie, Ghironi and Melitz (2006, 2007), it is quite natural to recommend central banks to stabilize the cross-sectional average inflation. The situation of perfect knowledge of the natural rate of interest, however, seems

PPI and CPI somehow misleading. There exist CPI indices all over the world, but none reflects the number of varieties. The index is computed as the average across different goods. Furthermore, the naming of average inflation seems also confusing with historical average inflation as in Nessen and Vestin (2005)

rather unrealistic.³² We evaluate the usefulness of welfare-based inflation targeting when the natural rate of interest is unknown to central banks.

Second, it is debatable whether the fiscal policy to eliminate real imperfections is available. Although not focused in the previous researches in this area, a very intriguing point is that endogenous entry causes real imperfections, a concept that introduced by Blanchard and Galí (2007), if appropriate fiscal policy is unavailable. Reflecting fluctuations in the number of varieties, the gap between the natural (flexible) and the efficient (Pareto optimal) level of output is no longer constant and variant to shocks.³³ For example, Bergin and Corsetti (2005) implicitly state this point as “However, the allocation in a flexible price equilibrium will not be in general Pareto optimal. There are three distortions in our economy: monopoly power in production, under or oversupply of varieties, and nominal rigidities. Correcting the first two distortions requires an appropriate set of taxes and subsidies. Only if these are in place, can monetary policy be effective in targeting the efficient allocation.” Similarly, Bilbiie, Gironi and Melitz (2006) summarize the types of distortions in a flexible price model with endogenous variety. In addition to the standard markup intertemporal dispersion³⁴ emerging even without nominal rigidity,³⁵ there exist “markup intra-temporal dispersion” and “non-synchronization of consumer

³²See, for example, Orphanides and Williams (2002).

³³For the definition of the natural and efficient output, see Chapter 6 of Woodford (2003).

³⁴This and monetary policy on this distortion are well summarized in Walsh (2003) or Woodford (2003).

³⁵This is coming from the endogenous elasticity of substitution stemming, for example, from the translog preference as in Feenstra (2003).

surplus and profit destruction.” Although we know how to tackle the first distortion by monetary policy, whether monetary policy can completely ignore the latter two distortions is not a trivial question. For example, Blanchard and Galí (2007) argue that “We focus on one such real imperfection, namely real wage rigidities. When the baseline new Keynesian model is extended to allow for real wage rigidities, the *divine coincidence* disappears, and central banks indeed face a trade-off between stabilizing inflation and the welfare-relevant output gap.” Previous studies, such as Bergin and Corsetti (2005) and Bilbiie, Ghironi and Melitz (2006, 2007), conclude that central banks should not target welfare-based inflation, that even contains information on the number of variety, but the cross-sectional average inflation. This is because they ignore the trade-off by assuming an appropriate fiscal policy. In a realistic economy, however, it is impossible to distinguish the natural the level of output from the efficient one. Furthermore, Bilbiie et al. (2006) note that “Importantly, since the wedges between the PO (Pareto Optimal) and CE (Competitive Equilibrium) are state-contingent, optimal policies aimed at closing these wedges will also be state contingent.” Yet, a state contingent fiscal policy with non-distortional tax is rarely available. It seems more realistic to assume that central banks aim at stabilize the welfare-relevant output gap, namely the gap between the actual and the efficient output, instead of the conventional output gap, namely the gap between actual and natural output. In that case, monetary policy targeting the welfare-based inflation may increase welfare through incomplete stabilization of markups. As we will see, real imperfections imply that inflation rates in the second best economy should not be fixed and non-zero. Therefore, lack of stabilization of the cross-sectional average

inflation may result in higher welfare by using inflation as a tax to control the optimal number of firms. Thus, following Blanchard and Galí (2007), we analyze the case when the central bank is the only institution to mitigate all distortions.

Thus, we re-think price stability in an economy with endogenous firm entry. We first demonstrate that the endogenous entry causes real imperfections. Reflecting fluctuations in the number of varieties, the gap between the natural and the efficient level of output is no longer constant and variant to shocks. As a result, central banks face a trade-off between stabilizing inflation and welfare-relevant output gap. Then, we show that this results in the non-zero optimal rate of inflation. We further examine whether welfare can be enhanced by targeting the welfare-based inflation instead of the cross-sectional average inflation, contrary to the findings in Bergin and Corsetti (2005) and Bilbiie, Ghironi and Melitz (2006, 2007), in two cases, namely when the natural rate of interest is unknown and the non-stochastic steady states are distorted. Simulations even with such distortions, however, support the cross-sectional average inflation targeting. Although incomplete stabilization enhances welfare in an economy when agents cannot internalize the externality on the love for variety,³⁶ there only exists small gains by referring also to the welfare-based inflation.

The rest of the paper is structured as follows. In Section 2, we show our model used for evaluating price stability under endogenous firm entry. Then, Section 3 provides that an economy with endogenous variety indeed contains real imperfections when the appropriate fiscal policy is not available. Section 4 discusses price stability

³⁶Implications of externalities including this type on the dynamic general equilibrium models are thoroughly analyzed in Kim (2004).

under endogenous firm entry. Three main results will be shown there. First, the optimal inflation rate under endogenous variety is usually non-zero. By manipulating inflation rates that act like a tax, central banks can correct sub-optimally high or low number of firms stemming from inability to endogenize externality.³⁷ Second, even under the situation where the central bank cannot observe the natural rate of interest, it is optimal to target the cross-sectional average rather than the welfare-based inflation. Third, such a policy remains still desirable even when non-stochastic steady states are distorted. Yet, small gains from incomplete stabilization can be expected by targeting some weighted average of the cross-sectional average and the welfare-based inflation. Finally, we summarize our main findings and state several future directions of research in Section 5.

3.2 Literature Review

As related studies, we first introduce the researches incorporating firm dynamics into the dynamic stochastic general equilibrium model. Then, we also refer to the studies that incorporate real imperfections and show the Ramsey optimal inflation rate can be non-zero.

Empirical studies in trade theory demonstrate strong pro-cyclical behavior of net producer entry, that cannot be explained without firm dynamics. Therefore, a model, that has more realistic assumption about firm dynamics and can explain the observed role of extensive margin in business cycles, is wanted. Among several researches in

³⁷It is assumed in this paper that there is no market for trading externality as supposed in Coase (1960).

line with this motivation, Bilbiie, Ghironi and Melitz (2005) inquire into the nature of a dynamic stochastic general equilibrium model with free entry and show that the performance of such models evaluated by the implied second moment properties are at least as good as the traditional model with fixed number of varieties. Bilbiie et al. (2006), on the other hand, analyze normative implication of endogenous variety. They recommend policy institutions to preserve the optimal amount of monopoly profits when firm entry is costly. Marginal cost pricing remains efficient only when the required sales subsidies are financed with the optimal split of lump-sum taxation between households and firms. Bilbiie et al. (2007), while summarizing main conclusions from above two papers, further show that inflation can act as a distortionary tax on firm profits and therefore be harmful to firm's incentive to create new goods. Similarly, Bergin and Corsetti (2005) analytically study the role of stabilization policy in a model with free entry. They show that monetary policy faces an additional role of controlling the optimal number of entrants. Their conclusion is, however, that the optimal monetary policy rule obtained in the dynamic new Keynesian model without entry remains to be optimal even under endogenous variety. Monetary policy that aims at marginal cost pricing, namely the cross-sectional average inflation targeting, remains desirable. On the other hand, reflecting recent actual increase in varieties, Broda (2004) concludes that "Measuring price changes accurately is central to the macroeconomic analysis used in conducting monetary policy. Various forms of bias in the consumer price index (CPI) have been documented in recent years, but a new form of bias tied to the introduction of new goods has only recently been explored empirically. Estimates of the 'new goods' bias suggest that CPI inflation has an

upward bias of 0.3 percentage point.”

As will be seen, we provide the optimality of the non-zero inflation targeting under the Ramsey planner. This result is indeed coming from real imperfections introduced by Blanchard and Galí (2007), the story here is very much analogous to trade-offs analyzed in Faia and Monacelli (2007) under the financial market imperfections and in Faia (2006) under the labor market frictions, and in open economies where “when financial markets are incomplete, and when there is only partial pass-through from exchange rate to prices” as summarized in Rogoff (2006). Furthermore, from the perspective of inability in endogenizing the externality, results in this paper are also very much related to Ljungqvist and Uhlig (2000) and Choudhary and Levine (2006). Both show higher tax rate is optimal since agents cannot internalize the externality stemming from external habit, namely the catching up with Joneses type preference.

3.3 Model

The model used in this paper is based on Bilbiie, Ghironi and Melitz (2005, 2006, and 2007). We examine cases with three different preferences,³⁸ namely CES preference of Dixit and Stiglitz (1977), that of Benassy (1996), and translog preference

³⁸This can be treated as the production function rather than preferences. Under this specification, however, increased range of intermediate goods shows up as increasing returns to specialization. As there exist empirical problems concerning increasing returns to specialization and CES production function, we treat this as preference. For details on this point, see footnote 22 in Bilbiie et al. (2006).

of Feenstra (2003). The first preference is abbreviated as the CES_DS preference in this paper. Elasticity of substitution and benefit of additional products under these three specifications are first shown in this section. Then, we derive the equilibrium conditions in three cases, namely under (monopolistically) competitive equilibrium, the Pareto optimal equilibrium, and the Ramsey policy.

3.3.1 Preferences

Since the form of the CES_DS nests on the CES preference as in Benassy (1996), we will only show the functions under CES and translog preferences.

CES The aggregator (utility function) is expressed as follows:

$$C_t = N_t^{\xi - \frac{\theta}{\theta-1}} \left[\int_0^{N_t} C_t(h)^{1-\frac{1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}}, \quad (36)$$

where h denotes the index for goods, C is the consumption, and N is the number of varieties. By minimizing the expenditure under the certain level of aggregate consumption, we can obtain the Hicksian demand function:

$$C_t(h) = N_t^{(\theta-1)(\xi - \frac{\theta}{\theta-1})} \left[\frac{P_t(h)}{P_t} \right]^{-\theta} C_t. \quad (37)$$

Substituting (37) into (36), the welfare-based price index is derived as the expenditure function:

$$P_t = N_t^{\frac{\theta}{\theta-1} - \xi} \left[\int_0^{N_t} P_t(h)^{1-\theta} dh \right]^{\frac{1}{1-\theta}}. \quad (38)$$

As obvious from (38), the price elasticity of demand ζ is constant as

$$\zeta_t^{CES} \equiv \frac{\partial C_t(h)}{\partial P_t(h)} \frac{P_t(h)}{C_t(h)} = \frac{\partial \log [C_t(h)]}{\partial \log [P_t(h)]} = \theta. \quad (39)$$

Hence, the markup under the flexible price equilibrium³⁹ is also constant as

$$\mu_t^{CES} \equiv \frac{\zeta_t^{CES}}{\zeta_t^{CES} - 1} = \frac{\theta}{\theta - 1}. \quad (40)$$

Under the symmetric equilibrium, the benefit of additional product variety ρ is derived as

$$\rho_t^{CES} \equiv \frac{P_t(h)}{P_t} = N_t^{\xi-1}, \quad (41)$$

and this can be also represented in the elasticity form as ε :

$$\varepsilon_t^{CES} \equiv \frac{\partial \rho_t}{\partial N_t} \frac{N_t}{\rho_t} = \frac{\rho_t'}{\rho_t} N_t = \xi - 1. \quad (42)$$

(41) and (42) demonstrate that ξ is the parameter for the taste for variety as shown in Benassy (1996). When $\xi > 1$, consumers obtain utility gain from additional variety. When $\xi = \frac{\theta}{\theta-1}$, namely the same as the markup as shown below, the preference collapses to the standard CES_DS, where the aggregator is defined as

$$C_t = \left[\int_0^{N_t} C_t(h)^{1-\frac{1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}}.$$

Translog Since the explicit form of the utility function cannot be provided, derivation of elasticity of substitution among goods and benefits from new goods is not straightforward as shown in Feenstra (2003) in detail. We herewith only show the results.

Under translog preference, the price elasticity of demand is no more constant as

$$\zeta_t^{TL} = 1 + \eta N_t, \quad (43)$$

³⁹As obvious from this equation, flexible price equilibrium is where there is no rigidity on cross-sectional average inflation rates, or no changes in markup.

where η is the parameter determining the price elasticity, and therefore, the markup under the flexible price equilibrium is expressed as

$$\mu_t^{TL} \equiv \frac{\zeta_t^{TL}}{\zeta_t^{TL} - 1} = 1 + \frac{1}{\eta N_t}. \quad (44)$$

The benefit of additional product variety now becomes

$$\rho_t^{TL} = \exp\left(-\frac{1}{2} \frac{\tilde{N} - N_t}{\eta \tilde{N} N_t}\right), \quad (45)$$

where \tilde{N} is the the total number of goods conceivably available, and that in the elasticity form is given by

$$\varepsilon_t^{TL} = \frac{1}{2\eta N_t} \quad (46)$$

3.3.2 Monopolistically Competitive Equilibrium

There are three agents in the economy, namely consumer, firms and the central bank. The former two agents are optimizing utility and profit respectively. On the other hand, the central bank sets nominal interest rates according to the Taylor (1993) type instrument rule. The optimizing central bank is considered under the Ramsey problem.

Consumer The representative consumer maximizes the life time welfare $Welf$ as

$$Welf_t = Util_t + \beta E_t Welf_{t+1}, \quad (47)$$

where β is the subjective discount factor and $Util$ is the instantaneous utility in the iso-elastic form as

$$Util_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}, \quad (48)$$

where h is the hours worked, σ is the relative risk aversion, φ is the Frisch elasticity of labor supply and χ determines the size of the steady state labor supply. The maximization is subject to the nominal budget constraint:

$$\frac{B_{t+1}}{P_t} + \frac{V_t}{P_t} N_{H,t} x_{t+1} + C_t = (1 + i_{t-1}) \frac{B_t}{P_t} + \frac{(D_t + V_t)}{P_t} N_t x_t + \frac{W_t}{P_t} h_t, \quad (49)$$

where B is the nominal debt, V is the value of the firm, namely the stock price, N_H is the firms already existing at time t , x is the share of holdings of such a stock, i denotes the short-term nominal interest rate set by the central bank, D is the nominal dividend and W is the nominal wage. In aggregate, naturally, $B = 0$ and $x = 1$.

First order necessary conditions are

$$C_t^{-\sigma} = \lambda_t, \quad (50)$$

$$\chi h_t^{\frac{1}{\varphi}} = \lambda_t w_t, \quad (51)$$

$$\lambda_t = \beta \mathbb{E}_t \frac{\lambda_{t+1} (1 + i_t)}{1 + \pi_{t+1}^C}, \quad (52)$$

$$\lambda_t v_t N_{H,t} = \beta \mathbb{E}_t \lambda_{t+1} (d_{t+1} + v_{t+1}) N_{t+1}, \quad (53)$$

where we define

$$\begin{aligned} w_t &= \frac{W_t}{P_t}, \\ d_t &= \frac{D_t}{P_t}, \\ v_t &= \frac{V_t}{P_t}, \\ 1 + \pi_t^C &= \frac{P_t}{P_{t-1}} = \frac{\rho_{t-1}}{\rho_t} (1 + \pi_t), \end{aligned} \quad (54)$$

and

$$1 + \pi_t = \frac{p_t}{p_{t-1}}.$$

π is the cross-sectional average inflation rate while π^C is the welfare-based inflation rate. In this paper, we assume the exogenous destruction of firms as⁴⁰

$$N_t = (1 - \delta)(N_{t-1} + N_{E,t-1}). \quad (55)$$

Therefore, $\delta \times 100\%$ of existing firms are assumed to exit from the market every period. By using (55) and, by definition,

$$N_{H,t} = N_t + N_{E,t}, \quad (56)$$

where N_E is the firm which enter the market at time t , we can rewrite (53) as

$$v_t = (1 - \delta) \beta \mathbf{E}_t \frac{\lambda_{t+1}}{\lambda_t} (d_{t+1} + v_{t+1}). \quad (57)$$

Furthermore, under the assumption of the symmetric equilibrium,

$$C_t + v_t N_{E,t} = w_t h_t + d_t N_t, \quad (58)$$

where we again use (56).

Firm Each firm in the monopolistically competitive market maximizes the value of the firm, namely

$$v_t + d_t,$$

subject to the demand y^D being equal to the supply y :

$$y_t = y_t^D$$

⁴⁰As will be discussed in the conclusion, the analysis under the endogenous firm destruction is our next research agenda.

where the value of the firms can be represented as the present discounted value of profit (dividend) by using pricing kernel:

$$v_t = \mathbb{E}_t \sum_{t=0}^{\infty} [(1 - \delta) \beta]^t \frac{\lambda_{t+1}}{\lambda_t} d_{t+1},$$

the profit is subject to the Rotemberg (1982) type price adjustment cost:

$$d_t = \frac{p_t}{P_t} y_t^D - w_t h_t - \frac{\kappa}{2} \left(\frac{p_t}{p_{t-1}} - 1 \right)^2 \frac{p_t}{P_t} y_t^D, \quad (59)$$

the linear production function:

$$y_t = Z_t h_t, \quad (60)$$

and the demand condition from the monopolistic competition:

$$y_t^D = \left(\frac{p_t}{P_t} \right)^{-\zeta_t} (C_t + PAC_t),$$

where PAC is the resource used for costly price changes:

$$PAC_t = N_t pac_t = N_t \frac{\kappa}{2} \left(\frac{p_t}{p_{t-1}} - 1 \right)^2 \frac{p_t}{P_t} y_t^D$$

Therefore, we can first obtain the first order necessary condition through the maximization with respect to h :

$$MC_t = \frac{w_t}{Z_t}, \quad (61)$$

Since the individual price can be expressed as

$$p_t = \mu_t MC_t P_t,$$

(61) is transformed into

$$\frac{p_t}{P_t} = \rho_t = \mu_t \frac{w_t}{Z_t}. \quad (62)$$

μ is the markup under the nominal rigidity and obtained by maximizing the value of the firm with respect to p :

$$\mu_t = \frac{\zeta_t}{(\zeta_t - 1) \left(1 - \frac{\kappa}{2}\pi_t^2\right) + \kappa \left[\pi_t (1 + \pi_t) - (1 - \delta) \beta \mathbb{E}_t \frac{1 - \frac{\kappa}{2}\pi_t^2}{1 - \frac{\kappa}{2}\pi_{t+1}^2} \frac{N_t}{N_{t+1}} \pi_{t+1} (1 + \pi_{t+1})\right]}, \quad (63)$$

where we use the conditions under the symmetric equilibrium:

$$Y_t^C \equiv C_t + PAC_t = N_t \frac{p_t}{P_t} y_t = N_t \rho_t y_t, \quad (64)$$

$$PAC_t = N_t pac_t = \frac{\kappa}{2} \pi_t^2 Y_t^C,$$

and

$$C_t = \left(1 - \frac{\kappa}{2}\pi_t^2\right) Y_t^C. \quad (65)$$

Under symmetric equilibrium, the profit is defined as follows:

$$d_t = \left(1 - \frac{1}{\mu_t} - \frac{\kappa}{2}\pi_t^2\right) \frac{Y_t^C}{N_t}. \quad (66)$$

Furthermore, firms that consider entering the market actually enter when the present discounted value of future profits is larger or at least as much as the fixed entry cost augmented by the labor income, namely $\frac{w}{Z} f_E$. As a result, the free entry condition is derived as follows:

$$\frac{w_t}{Z_t} f_{E,t} = v_t. \quad (67)$$

Monetary Policy First, we assume that the central bank sets the short-term nominal interest rate with the target level of inflation being zero. We will conduct several simulations using very simple instrument rules except for cases under the Ramsey policy planner where the steady state inflation rate is non-zero. We examine

two cases when the central banks know the natural (Vicksellian) rate of interest and not, with two possible references, namely the cross-sectional average and the welfare-based inflation rate. Therefore, in total, we examine four simple instrument rules as follows.

When the natural rate of interest is unknown, if the central bank targets the cross-sectional average inflation rate,

$$i_t = \frac{1 - \beta}{\beta} + \alpha\pi_t, \quad (68)$$

and if it targets the welfare-based inflation rate,

$$i_t = \frac{1 - \beta}{\beta} + \alpha\mathbf{E}_t\pi_{t+1}^C. \quad (69)$$

Welfare-based inflation rates that refer to the predetermined variable, namely the current number of firms (varieties), cannot be stabilized completely by central banks at the time when the shock hits the economy. Therefore, we employ the forecast based inflation targeting instrument rule when the central bank aims to stabilize the welfare-based inflation. On the other hand, when the natural rate of interest, defined as the real interest rate in the flexible price economy to be consistent with (52), namely $\frac{\lambda_t^*\pi_{t+1}^{C*}}{\beta\lambda_{t+1}^*} - 1$, is known, if the central bank targets the cross-sectional average inflation rate,

$$i_t = \left(\mathbf{E}_t \frac{\lambda_t^*\pi_{t+1}^{C*}}{\beta\lambda_{t+1}^*} - 1 \right) + \alpha\pi_t, \quad (70)$$

and if it targets the welfare-based inflation rate,

$$i_t = \left(\mathbf{E}_t \frac{\lambda_t^*\pi_{t+1}^{C*}}{\beta\lambda_{t+1}^*} - 1 \right) + \alpha\mathbf{E}_t\pi_{t+1}^C. \quad (71)$$

Since we only consider cases with complete stabilization, α is set to be very large. As a result, monetary policy with (70) produces the flexible price equilibrium allocation.⁴¹

Monopolistically Competitive Equilibrium A (monopolistically) competitive equilibrium model consists of 10 equations in Table 3.⁴²

Monopolistically Competitive Flexible Price Equilibrium Under the flexible price equilibrium, above monopolistically competitive equilibrium model is reduced to the system of 7 equations in Table 4.

3.3.3 Pareto Optimal Allocation

Social planner maximizes household utility as defined in (47) and (48) by acknowledging the fixed entry cost. As shown in the resource constraint in (64), the aggregate production function is now expressed as

$$Y_t = Z_t N_t \rho_t h_t. \quad (72)$$

The social welfare being consistent with that of the representative consumer in (47) and (48) is optimized subject to (72) and (MCEF7), the condition that determines the firm dynamics. From the first order conditions, we can obtain the intra-temporal optimality condition for labor:

$$C_t^{-\sigma} \rho(N_t) Z_t = \chi h_t^{\frac{1}{\varphi}}, \quad (73)$$

⁴¹The flexible price equilibrium in this paper shows the economy where there is no nominal rigidities on cross-sectional average inflation or no markup fluctuations.

⁴²Since the number of the firm is the only endogenous state variable, the model can be summarized to just a single equation.

Table 3: Monopolistically competitive equilibrium model

(MCE1):	$\zeta_t = \theta$ or $1 + \eta N_t$ from (39) or (43)
(MCE2):	$\rho_t = N_t^{\xi-1}$ or $\exp\left(-\frac{1}{2} \frac{\tilde{N}-N_t}{\eta \tilde{N} N_t}\right)$ from (41) or (45)
(MCE3):	$Util_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}$ from (48)
(MCE4):	$Welf_t = Util_t + \beta E_t Welf_{t+1}$ from (47)
(MCE5):	$\frac{\rho_t}{\mu_t} f_{E,t} = (1-\delta) \beta E_t \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \left[\frac{\left(1 - \frac{1}{\mu_{t+1}} - \frac{\kappa}{2} \pi_{t+1}^2\right) C_{t+1}}{\left(1 - \frac{\kappa}{2} \pi_{t+1}^2\right) N_{t+1}} + \frac{\rho_{t+1}}{\mu_{t+1}} f_{E,t+1} \right]$ from (62), (67), (66), (65), (50) and (57)
(MCE6):	$\chi h_t^{\frac{1}{\varphi}} = C_t^{-\sigma} Z_t \frac{\rho_t}{\mu_t}$ from (50), (62) and (51)
(MCE7):	$N_{t+1} = (1-\delta) \left[N_t + \frac{Z_t h_t}{f_{E,t}} - \frac{C_t}{\rho_t f_{E,t} \left(1 - \frac{\kappa}{2} \pi_t^2\right)} \right]$ from (62), (55), (66), (67), (65) and (35)
(MCE8):	$\mu_t = \frac{\zeta_t}{(\zeta_t - 1) \left(1 - \frac{\kappa}{2} \pi_t^2\right) + \kappa \left[\pi_t (1 + \pi_t) - (1 - \delta) \beta E_t \frac{1 - \frac{\kappa}{2} \pi_t^2}{1 - \frac{\kappa}{2} \pi_{t+1}^2} \frac{N_t}{N_{t+1}} \pi_{t+1} (1 + \pi_{t+1}) \right]}$ from (63)
(MCE9):	$\frac{C_t^{-\sigma}}{\beta E_t C_{t+1}^{-\sigma}} = \frac{1+i_t}{1+E_t \pi_{t+1}^C}$ from (50), (52), and (54)
(MCE10):	$i_t = \frac{1}{\beta} + \alpha \pi_t, \frac{1}{\beta} + \alpha E_t \pi_{t+1}^C, \left(E_t \frac{\lambda_t^* \pi_{t+1}^{C*}}{\beta \lambda_{t+1}^*} - 1 \right) + \alpha \pi_t$ or $\left(E_t \frac{\lambda_t^* \pi_{t+1}^{C*}}{\beta \lambda_{t+1}^*} - 1 \right) + \alpha E_t \pi_{t+1}^C$ from (68), (69), (70) or (71)

Table 4: Monopolistically competitive flexible price equilibrium model

(MCEF1):	$\zeta_t = \theta$ or $1 + \eta N_t$
(MCEF2):	$\rho_t = N_t^{\xi-1}$ or $\exp\left(-\frac{1}{2} \frac{\tilde{N} - N_t}{\eta \tilde{N} N_t}\right)$
(MCEF3):	$Util_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}$
(MCEF4):	$Welf_t = Util_t + \beta E_t Welf_{t+1}$
(MCEF5):	$\rho_t \frac{\zeta_t^{-1}}{\zeta_t} f_{E,t} = (1 - \delta) \beta E_t \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \left[\frac{1}{\zeta_{t+1}} \frac{C_{t+1}}{N_{t+1}} + \rho_{t+1} \frac{\zeta_{t+1}^{-1}}{\zeta_{t+1}} f_{E,t+1} \right]$
(MCEF6):	$\chi h_t^{\frac{1}{\varphi}} = C_t^{-\sigma} Z_t \rho_t \frac{\zeta_t^{-1}}{\zeta_t}$
(MCEF7):	$N_{t+1} = (1 - \delta) \left(N_t + \frac{Z_t h_t}{f_{E,t}} - \frac{C_t}{\rho_t f_{E,t}} \right)$

the intertemporal optimality condition for consumption:

$$C_t^{-\sigma} f_{E,t} \rho_t = (1 - \delta) \beta E_t C_{t+1}^{-\sigma} \left(f_{E,t+1} \rho_{t+1} + C_{t+1} \frac{\varepsilon_{t+1}}{N_{t+1}} \right), \quad (74)$$

and firm dynamics:

$$N_{t+1} = (1 - \delta) \left(N_t + \frac{Z_t h_t}{f_{E,t}} - \frac{C_t}{\rho_t f_{E,t}} \right). \quad (75)$$

The model under the Pareto optimal allocations is now expressed as in Table 5.

3.3.4 Ramsey Policy

The allocations and prices under the Ramsey optimal monetary policy⁴³ can be obtained by maximizing the social welfare defined in (47) and (48) subject to 9 equations consisting of (MCE1) to (MCE9). Such a problem is solved by maximizing

⁴³For the details of the Ramsey policy computed here, see Levin, Onatski, Williams and Williams (2005) and Christiano, Motto and Rostagno (2007b).

Table 5: Pareto optimal model

(PO1):	$\zeta_t = \theta$ or $1 + \eta N_t$
(PO2):	$\rho_t = N_t^{\xi-1}$ or $\exp\left(-\frac{1}{2} \frac{\tilde{N} - N_t}{\eta \tilde{N} N_t}\right)$
(PO3):	$Util_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}$
(PO4):	$Welf_t = Util_t + \beta E_t Welf_{t+1}$
(PO5):	$C_t^{-\sigma} f_{E,t} \rho_t = (1 - \delta) \beta E_t C_{t+1}^{-\sigma} \left(f_{E,t+1} \rho_{t+1} + C_{t+1} \frac{\varepsilon_{t+1}}{N_{t+1}} \right)$ from (74)
(PO6):	$\chi h_t^{\frac{1}{\varphi}} = C_t^{-\sigma} Z_t \rho_t$ from (73)
(PO7):	$N_{t+1} = (1 - \delta) \left(N_t + \frac{Z_t h_t}{f_{E,t}} - \frac{C_t}{\rho_t f_{E,t}} \right)$ from (75)
(PO8):	$\varepsilon_t = \xi - 1$ or $\frac{1}{2\eta N_t}$ from (42) or (46)

with respect to all the endogenous variables in the monopolistically competitive model including the short-term nominal interest rate controlled by monetary policy. Then, we can derive 10 new optimality conditions, most of which are those for Lagrangian multipliers on (MCE1) to (MCE9). We used the code working under the Dynare for the Ramsey policy routine used in Levin and Lopez-Salido (2003) and Levin et al. (2005).

3.3.5 Allocations under Fixed Labor

To focus on particular distortions, we will examine the case with fixed labor supply. In that case, h is constant and set to be unity, while the optimality conditions such as (MCE6), (MCEF6) and (PO6) are eliminated.

Table 6: Parameters

Parameter	Value	Description and Definitions
θ	3.8	Elasticity of substitution among goods
ξ	1.1, 2 or $\theta/\theta - 1$	Taste for variety
η	0.35323	Parameter for translog preference
β	0.99	Subjective discount factor
δ	0.025	Exogenous exit rate
\tilde{N}	100	Total number of goods conceivably available
σ	1	Intertemporal elasticity of substitution
φ	1	Frisch elasticity
κ	77	Rotemberg adjustment cost
χ	0.924272	Utility weight on labor
α	150	Monetary policy parameter
Z	1	Steady state technology level
f_E	1	Steady state entry cost

3.3.6 Parameters

We employ the calibrated parameters used in Bilbiie, Ghironi and Melitz (2005, 2006, 2007) except for the newly introduced parameter, the coefficient on the inflation gap in the instrument rule, that are set to be very large for complete stabilization. They are set as in Table 6.

3.4 Real Imperfections

Real imperfections are the concept that is defined by Blanchard and Galí (2007). Using the terminologies in Blanchard and Galí (2007), the Pareto optimal allocations and prices are called efficient while those under the flexible price equilibrium are defined natural. If the gap between the natural and the efficient output is constant, “stabilizing inflation is equivalent to stabilizing the welfare-relevant output gap.” This implies that if the gap is not constant and affected by monetary policy, there exist real imperfections where the central bank faces the trade-off between the stabilizing nominal and real variables.

In a standard new Keynesian model well summarized in Walsh (2003) and Woodford (2003), the difference between the efficient and the natural allocation is always constant and cannot be controlled by monetary policy through nominal interest rates. It is optimal for central banks to aim at completely stabilizing inflation rates even under the distorted steady state when the appropriate fiscal policy is unavailable.⁴⁴ For example, under the flexible price equilibrium with the CES_DS preference, the iso-elastic utility function in (48), the linear production function as (60), and the optimality condition for the labor supply, we can obtain the consumption level under the monopolistically competitive market C^{MCE} :

$$C_t^{MCE} = \left(\frac{\theta - 1}{\chi\theta} Z_t^{1+\frac{1}{\varphi}} \right)^{\frac{\varphi}{1+\varphi\sigma}}, \quad (76)$$

⁴⁴Cost push shock can be considered as the source of the real imperfections since it can make the real variables time-varying through the markup.

while the counter part in (76) under the Pareto optimal allocation C^{PO} is

$$C_t^{PO} = \left(\frac{1}{\chi} Z_t^{1+\frac{1}{\varphi}} \right)^{\frac{\varphi}{1+\varphi\sigma}}. \quad (77)$$

The log difference between C^{MCE} and C^{PO} is always constant as $\frac{\varphi}{1+\varphi\sigma} \log\left(\frac{\theta-1}{\theta}\right)$. Furthermore, clearly real interest rates do not have any influence on this difference since consumption is solely determined by the exogenous state variable.⁴⁵ Therefore, irrespective of the economy is at the efficient steady state or not, the central bank should aim at price stability since there exists no real imperfections in the standard new Keynesian model without a cost push shock. This property of the standard new Keynesian model is named as the divine coincidence by Blanchard and Galí (2007). We will show that this condition does not necessarily hold under the economy with endogenous variety.

3.4.1 Analytical Comparison

Contrary to the standard new Keynesian model, we can encounter real imperfections with firm entry. Except for the case with the CES_DS preference, the economy shows real imperfections even only with a single shock that expands production frontier outwards. Following Bilbiie, Ghironi and Melitz (2006, 2007), we first explain three distortions that divert allocations under the monopolistically competitive flexible price equilibrium from those under the social planner's optimization. Then, we further show that even under monopolistic competition, if the preference is the CES_DS and the labor supply is fixed, the Pareto optimal allocations coincide with

⁴⁵(76) and (77) are policy functions.

those under the monopolistically competitive flexible price equilibrium.

By comparing the equilibrium conditions under the monopolistically competitive flexible price equilibrium to those under the Pareto efficient allocation, we can find three differences. The first is the differences in the intra-temporal optimality conditions for the labor supply namely in (MCEF6) and (PO6):

$$\text{(MCEF6): } \chi h_t^{\frac{1}{\varphi}} = C_t^{-\sigma} Z_t \rho_t \frac{\zeta_t - 1}{\zeta_t},$$

$$\text{(PO6): } \chi h_t^{\frac{1}{\varphi}} = C_t^{-\sigma} Z_t \rho_t.$$

This distortion is coming from the existence of the markup under the monopolistically competitive flexible price equilibrium. As shown in detail in Bilbiie et al. (2006), this reflects the different markups for different final products, namely consumption goods and leisure here. This supports the finding in Lerner (1934) that “If the social degree of monopoly is the same for all final products there is no monopolistic alteration from the optimum at all.” Intuitively, due to the differences in markups, some goods are consumed at sub-optimally high level while others are at sub-optimally low level. Therefore, differences in markup naturally cause the welfare loss. We call this “markup intra-temporal dispersion.”

Other two distortions can be found in the intertemporal optimality conditions, namely between (MCEF5) and (PO5) together with (PO8):

$$\text{(MCEF5): } \rho_t \frac{\zeta_t - 1}{\zeta_t} f_{E,t} = (1 - \delta) \beta \mathbf{E}_t \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \left[\frac{1}{\zeta_{t+1}} \frac{C_{t+1}}{N_{t+1}} + \rho_{t+1} \frac{\zeta_{t+1} - 1}{\zeta_{t+1}} f_{E,t+1} \right]$$

$$\text{(PO5) with (PO8): } C_t^{-\sigma} f_{E,t} \rho_t = (1 - \delta) \beta \mathbf{E}_t C_{t+1}^{-\sigma} \left(C_{t+1} \frac{\xi - 1}{N_{t+1}} + f_{E,t+1} \rho_{t+1} \right) \text{ or}$$

$$(1 - \delta) \beta \mathbf{E}_t C_{t+1}^{-\sigma} \left(C_{t+1} \frac{1}{2\eta N_{t+1}^2} + f_{E,t+1} \rho_{t+1} \right)$$

As formally derived in Bilbiie et al. (2006), both allocations coincide⁴⁶ when markup

⁴⁶This is at least true for the non-stochastic steady state and dynamics in the linearized system.

is synchronized over time and across goods⁴⁷ and the consumer surplus and profit destruction effects are balanced. Bilbiie et al. (2006) term the former distortion as “markup intertemporal distortion” and the latter as “non-synchronization of consumer surplus and profit destruction.” As is obvious from (39), these two conditions are satisfied when the preference is the CES_DS, namely when the parameter of the taste for variety is equal to the markup. Intuitively, this implies that the gains from additional utility from another new goods is the same as the firm’s incentive to obtain profit by creating a new product. As we will see, if the former is larger (smaller), the economy ends up with sub-optimally low (high) number of firms.

Therefore, unless the preference is the CES_DS and the labor is fixed, there exists a wedge between the allocations under the monopolistically competitive flexible price equilibrium and the Pareto optimal equilibrium. The economy under firm dynamics can produce real imperfections. This gap can be time-varying and affected by monetary policy.

3.4.2 Numerical Comparison

In this subsection, we first examine the case under exogenous labor supply to focus on the role of two distortions, namely markup intertemporal distortion and non-synchronization of consumer surplus and profit destruction. We will compare the paths from three preference specifications, namely the CES in Benassy (1996), the CES_DS and the translog, in four situations, namely, under the Pareto optimal, the Ramsey optimal, the flexible price, and the welfare-based inflation stabilized

⁴⁷For details, see footnote 18 of Bilbiie et al. (2006).

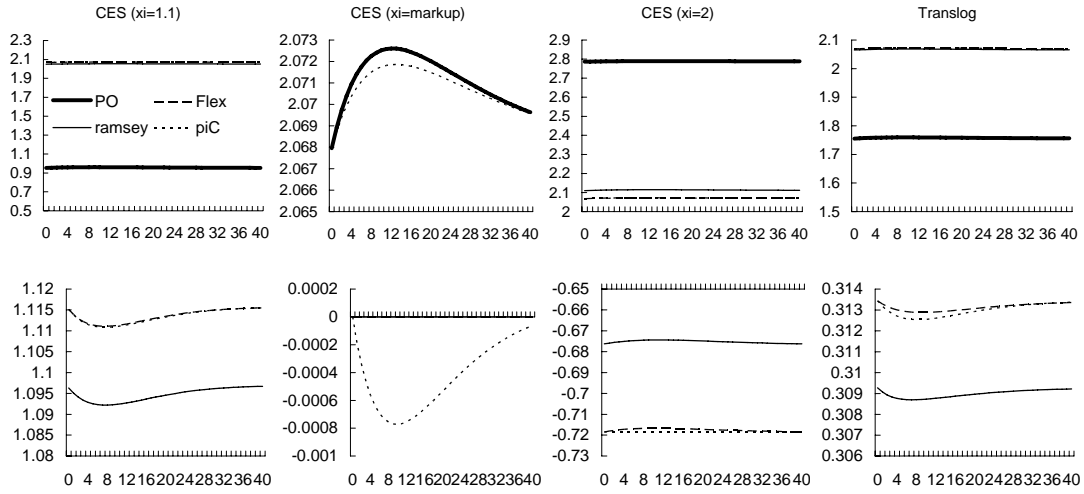


Figure 11: Productivity gain

allocations. The third one is the outcomes under the monopolistically competitive flexible price equilibrium or the monopolistically competitive equilibrium when the instrument rule is (70). The last allocation is computed under the monopolistically competitive equilibrium with monetary policy as (71). Since the only endogenous state variable considered in this paper is the number of firms, we only show its dynamics. We examine both productivity and efficiency gains as shocks with autocorrelation of 0.9. As shown in Corsetti, Martin and Pesenti (2007), the former has direct effects on the marginal cost while the latter has indirect effects on the aggregate price index through the number of varieties. We examine both shocks to obtain robust results irrespective of shock nature.

Exogenous Labor Supply Figure 11 shows the level responses of the number of firms for the positive productivity gains, namely the standard positive TFP shock. Upper charts show the responses in the log level while lower charts demonstrate the

(log) differences from the Pareto optimum equilibrium. There are several intriguing findings. First, if the taste for variety is larger (smaller) than the markup, there exist too few (many) firms or sub-optimally low (high) numbers of varieties in the economy. Mathematically, this can be understood by comparing the intertemporal optimality conditions as in the previous subsection. This is due to inability of agents to internalize the externality stemming from more variety. For example, although the utility gain from additional variety is very large when the taste for variety is high, due to the constant markup on the consumer goods, sub-optimally low number of firms only find it optimal to enter the market. Second, with the translog preference, the number of firms is sub-optimally high in the competitive equilibrium. Bilbiie et al. (2006) explain this as “The benefit of variety is only half the net markup for any N , so the competitive equilibrium features a sub-optimally high number of firms.” Third, when the preference is the CES_DS, as explained in the previous subsection, the Pareto optimal allocations coincide with those under the monopolistically competitive equilibrium and therefore those under the Ramsey optimal policy. Hence, it is optimal for the central bank to completely stabilize the cross-sectional average inflation since the divine coincidence applies to this economy. Fourth and most importantly, except for the case with the CES_DS preference, the Ramsey policy allocations are different from those under the flexible price equilibrium. Furthermore, the gap between the latter and the Pareto optimal allocation is time-varying. Since the steady states under the Ramsey policy are different from the complete inflation stabilization cases, it is not trivial which of the two targeting schemes, namely the cross-sectional average inflation or the welfare-based inflation targeting, is superior,

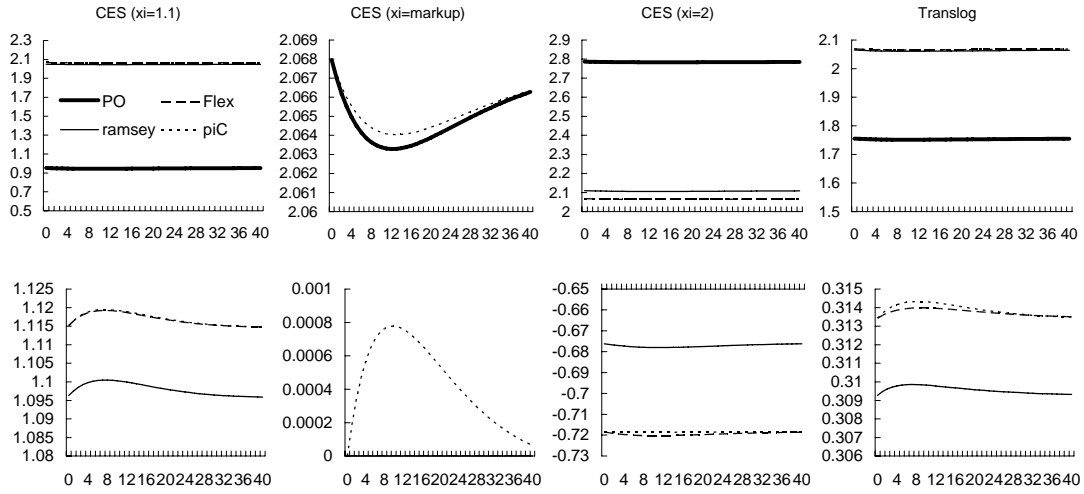


Figure 12: (Negative) Efficiency gain

by just comparing the impulse responses to those under the Ramsey policy. At least, we can, however, state that the central bank faces a trade-off from additional distortions that cannot be completely eliminated only by stabilizing the cross-sectional average inflation rate. We will inquire into this more carefully in the next section.

Responses for the negative efficiency gains for entry, namely an increase in the entry cost, are shown in Figure 12. Almost similar results are obtained with this case. Depending on the preferences, the number of firms can be sub-optimally high or low and there exists real imperfections except for the case with the CES_DS preference.

Endogenous Labor Supply Here, to solely focus on the markup intra-temporal distortion, we only experiment the case with the CES_DS preference. Figure 13 demonstrates the responses for both productivity and efficiency gains. The important finding here is that even when there is an additional distortion and the gap between the Pareto optimal equilibrium and the competitive equilibrium is time-varying,

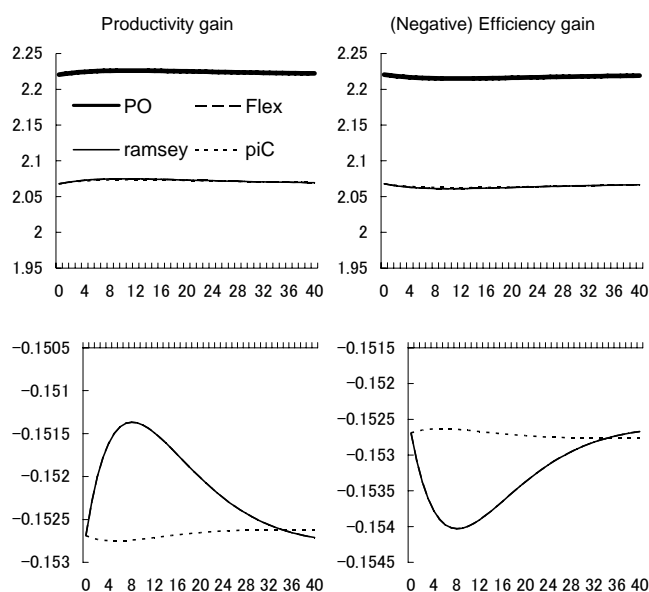


Figure 13: Endogenous labor supply

responses under the Ramsey monetary policy is exactly the same as those under the flexible price. The markup intra-temporal distortion itself does not imply real imperfections at all for monetary policy. This is what Bergin and Corsetti (2005) describe as “lack of stabilization is surely detrimental to welfare.” Hence, as the endogenous labor itself is not very intriguing for re-thinking price stability even under the distorted steady states, we will concentrate on the outcomes with the fixed labor supply in the analyses below.

3.5 Price Stability under Firm Entry

So far, we have seen that real imperfections likely occur in an economy with firm entry. Hence, monetary policy should play an additional role other than the cross-sectional average inflation stabilization. Now, we are to scrutinize price stability

in an economy with endogenous firm entry. First, we will show the optimal rate of inflation in an economy with endogenous variety under distorted non-stochastic steady states. Then, we would like to challenge the conclusion by Bergin and Corsetti (2005) and Bilbiie et al. (2007) that central banks should aim to stabilize the cross-sectional average inflation rather than the welfare-based inflation rate from several different perspectives, namely from inability to monitor the natural rate of interest, and from the distorted non-stochastic steady states stemming from unavailability of appropriate fiscal policy.

3.5.1 Optimal Rate of Inflation

Impulse responses in the previous section show that the steady states of the Ramsey optimal allocation are different from those under zero inflation steady states. This suggests that the optimal rate of inflation should be non-zero.⁴⁸ The optimal inflation rates for three intriguing cases, namely with preferences except for the CES_DS, examined in the previous section are summarized as in the Table 7. The results show that when the number of firms is sub-optimally high (low), the optimal inflation rate in the second-best economy is positive (negative). The mechanism that yields the non-zero optimal level of inflation in this paper is quite different from the classical

⁴⁸Possibly non-zero optimal inflation rate under the economy with firm entry without fiscal remedy is not a new idea. It is mentioned already mentioned in Bilbiie et al. (2007) that “The (Ramsey) optimal rate of inflation would be non-zero in a second-best environment in which lump-sum instruments are unavailable. The monetary authority would trade the welfare cost of inflation against the welfare costs of markup variation coming from both a time-varying elasticity of substitution and the misalignment of the benefit of extra variety with the profit incentive provided by markup.”

Table 7: Optimal inflation rate

CES ($\xi = 1.1$)	CES ($\xi = 2$)	Translog
0.64%	-1.5%	0.26%

argument of inflation bias stemming from the discretion by the central bank. In this paper, the optimal non-zero inflation rate is obtained in a situation where the central bank can make credible commitment. Furthermore, even under the commitment, it is different from the one in Khan, King and Wolman (2003). Khan et al. (2003) incorporate the costly exchange of wealth for consumption and obtain non-zero optimal inflation rate as a result of tension between relative price distortions stemming from Calvo (1983) and the Friedman (1969) rule.

Let us first concentrate on the positive optimal inflation rate. The basic reason for this is that, as mentioned in Bilbiie et al. (2007), inflation acts like a tax on firm profits. (MCE7) clearly shows that the number of varieties becomes smaller when inflation rates are also higher. This becomes more evident if we look into (66). In this setting of the Rotemberg type adjustment cost, any positive inflation results in decrease in firm profits.⁴⁹ Thus, in a situation where inflation turns out to be costs on profit, the steady state inflation is used as an instrument by the central bank to close the gap between the Pareto and the Ramsey optimal allocation. The central bank

⁴⁹Note that if firms acknowledge the trend inflation and pay no cost in the price changes according to the trend inflation, the optimal inflation remains zero. Hence, the optimal rate of inflation becomes closer to zero if we employ such pricing mechanisms as endogenous contracts duration in Levin and Yun (2007) or endogenous indexation in Mash (2007).

trade the welfare cost of inflation against that of markup variations stemming from the misalignment of the benefit of extra variety with the profit incentives provided by the markup. Basically the model in this paper can be summarized in two equations as (MCE5) and (MCE7) in the monopolistically competitive equilibrium or (PO5) and (PO7) under the Pareto optimal allocations. The steady state values for the number of variety and consumption in the former are now expressed as

$$N = \left[\frac{1 - (1 - \delta) \beta}{(1 - \delta) \beta \mu \left(1 - \frac{1}{\mu} - \frac{\kappa}{2} \pi^2\right)} + \frac{\delta}{1 - \delta} \right]^{-1}, \quad (78)$$

and

$$C = \left(1 - \frac{\kappa}{2} \pi^2\right) \left[N^{\xi-1} - \frac{\delta}{1 - \delta} N^{\xi} \right], \quad (79)$$

while those for the latter are

$$N = \left[\frac{1 - (1 - \delta) \beta}{(1 - \delta) \beta (\xi - 1)} + \frac{\delta}{1 - \delta} \right]^{-1}, \quad (80)$$

and

$$C = N^{\xi-1} - \frac{\delta}{1 - \delta} N^{\xi}, \quad (81)$$

where we substitute steady state benefits of additional product variety under the CES preference. Clearly, with the CES_DS preference, zero inflation results in the same allocations. With the CES preference in Benassy (1996),⁵⁰ however, if the Ramsey planner try to decrease the number of firms to the level in the Pareto optimal allocation by setting positive steady state inflation, it ends up with lower consumption as shown in (79). Compared to the fiscal prescriptions raised in Bilbiie et al. (2006) that directly work through (MCE5) or (78), the term for the allocation

⁵⁰Similar results hold for the case with the translog preference.

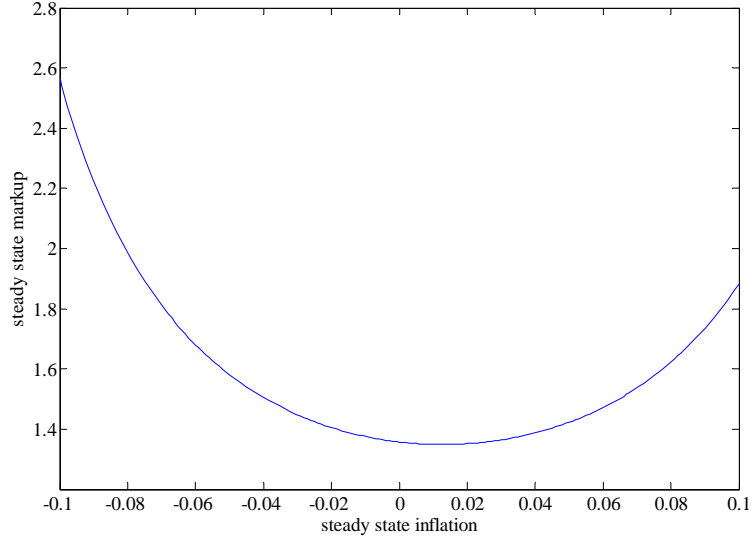


Figure 14: Steady state markup

of resources for costly prices changes in (MCE7) or (79) makes the central bank to face such a trade-off.

The reason for the optimal negative steady state inflation is less obvious, since any non-zero inflation seems to result in decrease in firm profits and therefore in number of firms as well as consumption according to (78) and (79). Yet, the negative steady state inflation increases firm profits and number of firms through the markup in (78). By eliminating time subscripts in (MCE8), we can express the steady state markup as

$$\mu = \frac{\theta}{(\theta - 1) \left(1 - \frac{\kappa}{2} \pi^2\right) + \kappa [1 - (1 - \delta) \beta] \pi (1 + \pi)}.$$

Figure 14 shows how the steady state markup differ as the steady state inflation changes. Clearly, there exists asymmetry between positive and negative steady state inflation rates. The steady state markup always increases as the steady state deflation

becomes larger. Since this effect through the steady state markup dominates that through the profit directly, the negative steady state inflation rate can correct the sub-optimally small number of firms and low consumption.

To summarize, by facing the trade-off between inflation stabilization and the misalignment of taste for variety and profit incentive, the central bank as the Ramsey planner chooses some optimal level of steady state inflation. This new role of the steady state inflation rate is absent in the standard new Keynesian model with fixed variety. The story here is quite similar to the justification of the positive capital income tax rate when the asset market is incomplete. As shown by Aiyagari (1995), agents save more under the Bewley (1977) type economy since they need to prepare for the uninsured idiosyncratic shocks by self-insurance. As a result, a positive capital income tax rate reduces the sub-optimally high capital level and is therefore welfare-enhancing. In our model, the only endogenous state variable is the number of firms while it is capital in Aiyagari (1995). In both cases, sub-optimally high level of state variables can become smaller by introducing the tax on profit.

From the perspective of inability in endogenizing the externality, this results can also be considered analogous to Ljungqvist and Uhlig (2000), Choudhary and Levine (2006), and Faia (2006). Ljungqvist and Uhlig (2000) and Choudhary and Levine (2006) show higher tax rate is optimal since agents cannot internalize the externality stemming from external habit, namely the catching up with Joneses type preference. Faia (2006) analyze the optimal monetary policy under the matching frictions that feature a congestion externality.

The analysis in this subsection suggests that it is of great importance for the

central bank to acknowledge whether the level of the aggregate endogenous state variables is sub-optimally high or low. Depending on this results, the optimal inflation rate as a tax device should become quite different.

3.5.2 Cross-sectional Average Inflation versus Welfare-based Inflation

Current consensus view is that monetary policy in an economy with firm dynamics should also stabilize the cross-sectional average inflation instead of the welfare-based inflation rate. Bergin and Corsetti (2005) conclude that “the goal of (welfare-based) CPI stability may not be a good target for policy makers. To the extent that it is desirable to support a flex price allocation, monetary authorities should stabilize firms’ marginal costs and product prices, not the CPI. The price level should instead move freely with entry, providing information about fluctuations in consumption utils which – given prices– households enjoy.” Similarly, Bilbiie et al. (2007) insist that “Optimal monetary policy stabilizes producer prices but lets the consumer price index vary to accommodate changes in the number of available products.” On the other hand, reflecting the recent increase in varieties found in the data,⁵¹ Broda (2004) concludes that “Measuring price changes accurately is central to the macroeconomic analysis used in conducting monetary policy. Various forms of bias in the consumer price index (CPI) have been documented in recent years, but a new form of bias tied to the introduction of new goods has only recently been explored empirically. Estimates of the ‘new goods’ bias suggest that CPI inflation has an upward bias of 0.3 percentage point.”

⁵¹For details in this empirical finding, see Broda and Weinstein (2006).

What is the source of these different views on monetary policy in an economy with endogenous variety? There exist two possible explanations for these divergent views. The first is concerning the actual implementation of monetary policy. What Bergin and Corsetti (2005) and Bilbiie et al. (2007) recommend when the tax policy is available to eliminate the real imperfections is that monetary policy should stabilize markup fluctuations. Although how to implement such a policy through an interest rate rule is mentioned in Bilbiie et al. (2007), the central bank is assumed to have complete knowledge about the natural rate of interest, that is the real interest rate in the flexible price equilibrium. Under such circumstances, it is quite natural that the central bank should solely stabilize the cross-sectional average inflation rate. The most important reason why the central bank should possibly target the welfare-based inflation is to precisely know the pricing kernel, namely the marginal utility out of consumption denominated by the welfare-based inflation, that determines the natural rate of interest. Therefore, in the first experiment in this subsection, we consider the case without any real imperfections in non-stochastic steady states where the allocations under the social planner coincides with those under competitive market equilibrium, but the central bank cannot observe the natural rate of interest completely. That is the case with fixed labor under the CES_DS preference where monetary policy is the sole source of dynamic distortions under the central bank with incomplete knowledge about the pricing kernel. In this experiment, it is assumed that the central bank has knowledge only about the steady state real interest rate, that is $(1 - \beta)/\beta$ as in (68) and (69).

The second possibility is on the realistic implementation of the public policy. It

is mentioned in Bilbiie et al. (2006) that “Importantly, since the wedges between the PO and CE are state-contingent, optimal policies aimed at closing these wedges will also be state contingent.” Although some optimal tax policy turns out to be not state-contingent, realistically it is still questionable whether the fiscal authority can actually implement such a policy with non-distorting lump sum taxation. Therefore, in the second experiment, we provide which inflation the central bank should stabilize, the cross-sectional average inflation versus the welfare-based inflation, by setting the steady state inflation at its Ramsey optimal level. Welfare-based inflation stabilization means lowering nominal interest rates when the number of firms increases. Therefore, it does not necessarily imply the control of the optimal number of firms. Monetary policy targeting welfare-based inflation can, however, increase welfare through incomplete stabilization. Real imperfections imply that inflation rates in the second best economy should not be fixed at some targeted level. Inflation rates as a tax can be used by the Ramsey policy planner, namely the central bank, as a tool to control the number of firms so that the economy becomes closer to the Pareto optimal situation. Therefore, lack of stabilization of the cross-sectional average inflation may result in higher welfare.

Efficient Steady States If the central bank cannot observe the natural rate of interest, welfare-based inflation targeting can be welfare-enhancing since the welfare-based price level contains information on the pricing kernel. As shown in (70), under the symmetric equilibrium, the optimal interest rate rule in an economy with efficient steady states incorporates the dynamics of welfare-based inflation albeit in the

Table 8: Welfare comparison

seed	Productivity gain		Efficiency gain	
	π	π^C	π	π^C
1	51.229	51.227	51.204	51.204
2	51.218	51.217	51.211	51.211
3	51.202	51.202	51.222	51.220
4	51.217	51.216	51.211	51.211
5	51.205	51.205	51.220	51.219

flexible price equilibrium. Therefore, (69),⁵² that is the expected welfare-based inflation targeting rule to be consistent with the stochastic discount factor, can mitigate real imperfections better than the stabilization policy on the cross-sectional average inflation as in (68).

First, we compute the welfare as the value in stochastic steady states in a second order approximated model.⁵³ The Table 8 shows the welfare in both rules as (68) and (69) for 100,000 sample in each first five seed in Dynare when the size of one percentage standard error is given. In all cases examined here, welfare is higher with the standard stabilization policy on the cross-sectional average inflation rates even

⁵²Another possible specification is that including lagged nominal interest rates, usefulness of which is stressed in Orphanides and Williams (2002).

⁵³We solve this problem using Dynare. Following Kim and Kim (2007), we approximate all equations including the welfare measure up to the second order. For details, see Kim, Kim, Schaumburg and Sims (2003) and Schmitt-Grohé and Uribe (2004).

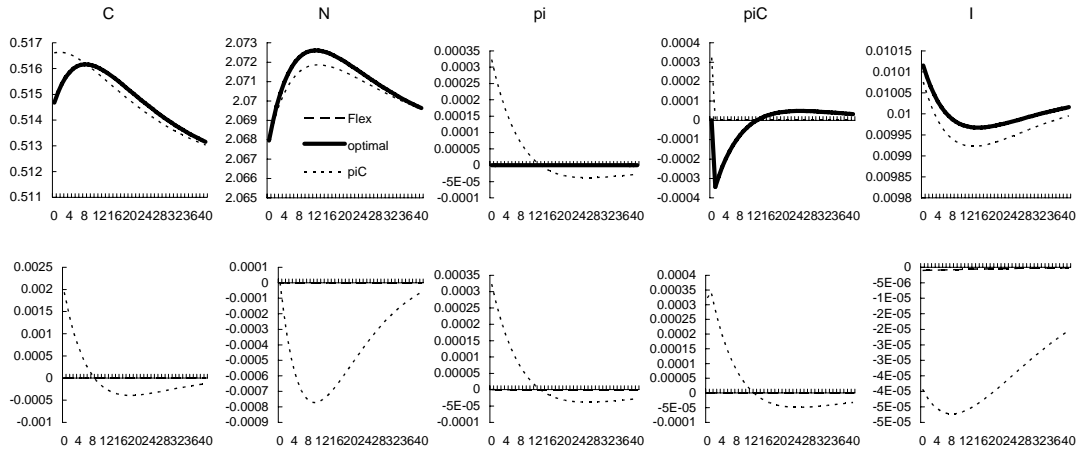


Figure 15: Productivity gain

though the natural rate of interest is unknown. Figure 15 shows the responses for the productivity gain for different instrument rules. Again, upper charts show the responses in the log level while lower charts demonstrate the (log) differences from the Pareto optimum equilibrium. Responses under the flexible price equilibrium is very close to those obtained under the social planner's optimization. Although a slight departure from the Pareto optimal equilibrium can be found, for example, in responses in nominal interest rates, it is minuscule and the departure in the same direction is much worse under the welfare-based inflation stabilization than under the cross-sectional average inflation stabilization. Similar results can be observed in Figure 16. Again, allocations and prices under the flexible price equilibrium are much closer to those under the social planner's optimization problem. Yet, lower charts show that the direction of the log differences from the Pareto optimal allocation is different in nominal interest rates. This shows a welfare-deteriorating effects of the strict cross-sectional average inflation targeting in an economy with unknown

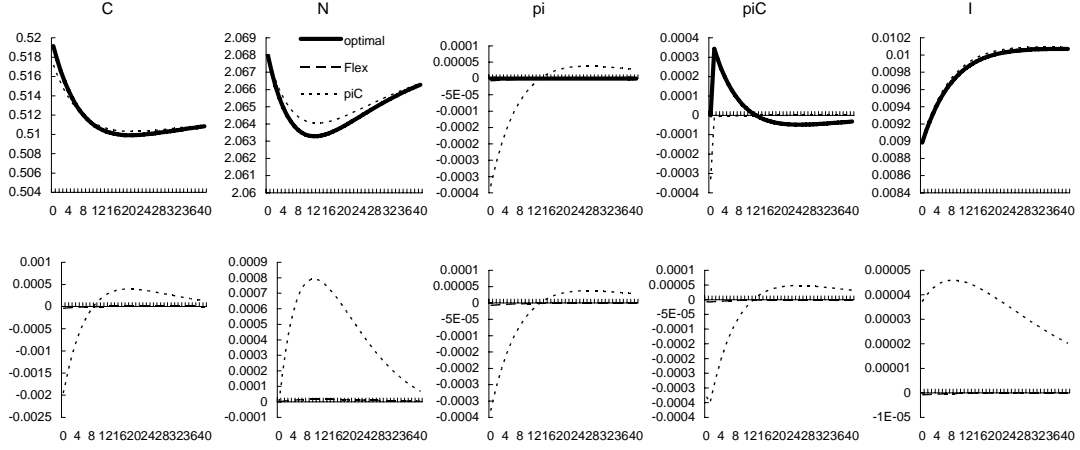


Figure 16: (Negative) Efficiency gain

natural rate, but the gain from further referring to welfare-based inflation is very minuscule. This result implies that the relative weights on welfare-based inflation, namely the power $1/(\theta - 1)$ in (54), may be sub-optimally high. As the weight on the firm dynamics becomes smaller with larger θ in (54), targeting welfare-based inflation can be more welfare-improving when goods are very much substitutable.

Ramsey Steady State As analyses in previous section show, due to non-zero steady state inflation, steady states under the Ramsey policy planner are different from those under both zero inflation stabilization rules. To be able to compare those responses so that we can learn whether the central bank should target the cross-sectional average or the welfare-based inflation rate, we alter the instrument rules in (68) and (69) as follows:

$$i_t = \frac{1 - \beta}{\beta} + \pi^{RO} + \alpha (\pi_t - \pi^{RO}),$$

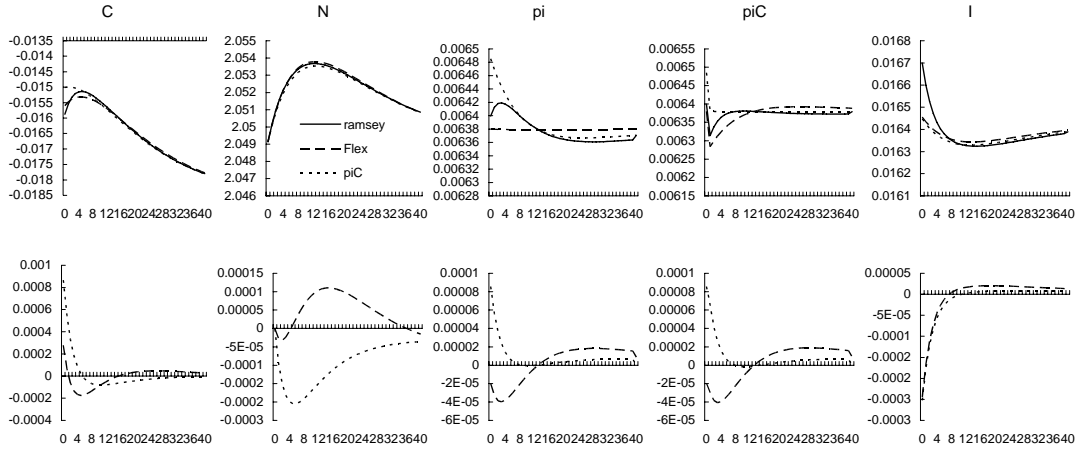


Figure 17: Productivity gain

and

$$i_t = \frac{1 - \beta}{\beta} + \pi^{RO} + \alpha E_t (\pi_{t+1}^C - \pi^{RO}),$$

where π^{RO} is optimal inflation rates under the Ramsey social planner.⁵⁴ The influential researches on the optimal monetary policy by Benigno and Woodford (2005) and Schmitt-Grohé and Uribe (2006) recommend the central bank to employ the optimal monetary policy around the steady state under the Ramsey policy. Hence, we evaluate the validity of above two instrument rules by testing which inflation targeting rule, namely the cross-sectional average inflation or the welfare-based inflation targeting, is closer to the pass suggested by the Ramsey policy planner.

CES ($\xi = 1.1$) Figure 17 shows the responses for the productivity gain. Again, upper charts show the level responses in logs while lower charts demonstrate the (log) differences from variables under the Pareto optimal policy. Interestingly, infla-

⁵⁴Almost no differences are found even if we use the specifications as in (70) and (71).

tion is not fixed even in the Ramsey policy. This implies real imperfections. Since a constant markup is derived under the CES preferences, the non-synchronization of consumer surplus and profit destruction alone makes the central bank to face a trade-off between stabilizing real and nominal variables. As analyzed in the section for real imperfections, efficient allocation cannot be achieved since the intertemporal optimality conditions are different in the social planners problem and in the competitive equilibrium as shown in (MCEF5) and (PO5). Bilbie et al. (2006) show that some tax policies can change the relationship in (MCEF5) directly so that it becomes the same as (PO5). In such a situation, the optimal policy is complete stabilization of the cross-sectional average inflation rate. The correction of the steady state inflation here does, however, not have direct effects on intertemporal optimality conditions. It works through the firms dynamics via profits in (MCE5). Furthermore, we can not reach the Pareto optimal allocations just by manipulating steady state inflation as shown in detail in (78) to (81). Hence, central banks makes inflation rates fluctuate so that it can control the number of firms to be close to the Pareto optimal allocations. As a result, the Ramsey policy implies the fluctuating inflation. As this is indeed coming from real imperfections, the story here is very much analogous to trade-offs analyzed in Faia and Monacelli (2007) under the financial market imperfections and in Faia (2006) under the labor market frictions, and in open economies where “when financial markets are incomplete, and when there is only partial pass-through from exchange rate to prices” as summarized in Rogoff (2006).

More importantly, allocations and prices under the flexible price equilibrium are more similar to those under the Ramsey planner. Therefore, in accordance with

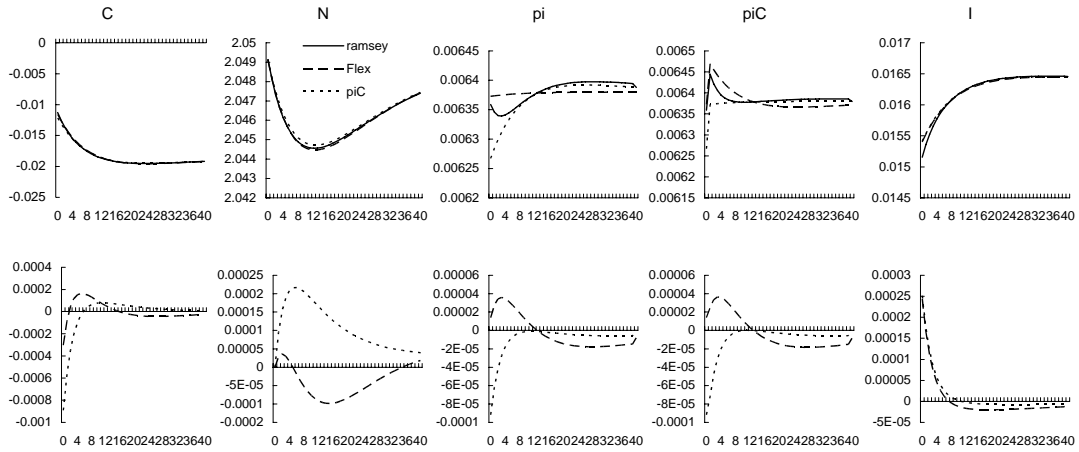


Figure 18: (Negative) Efficiency gain

previous researches, a policy aiming at reaching to the flexible price equilibrium is better in welfare than that to stabilize welfare-based inflation. Yet, at the same time, movements under the Ramsey policy is somewhere between those under the cross-sectional average and those under the welfare-based inflation targeting. Similar to the last case in the analysis above suggests, the weight in the instrument rule, namely $\frac{1}{\theta-1}$, seems to be too large for welfare-based inflation to be targeted.

Figure 18 shows the responses to the negative efficiency gain. As stated above, by targeting the cross-sectional average inflation, the economy becomes closer to the one under the Ramsey policy planner. Central banks may, however, gain by targeting the weighted average of the cross-sectional average inflation and the welfare-based inflation rate.

CES ($\xi = 2$) The responses in the CES preference when the taste for variety is high is shown as in Figures 19 and 20. These two charts also support the welfare dominance of the stabilization policy on the cross-sectional average inflation.

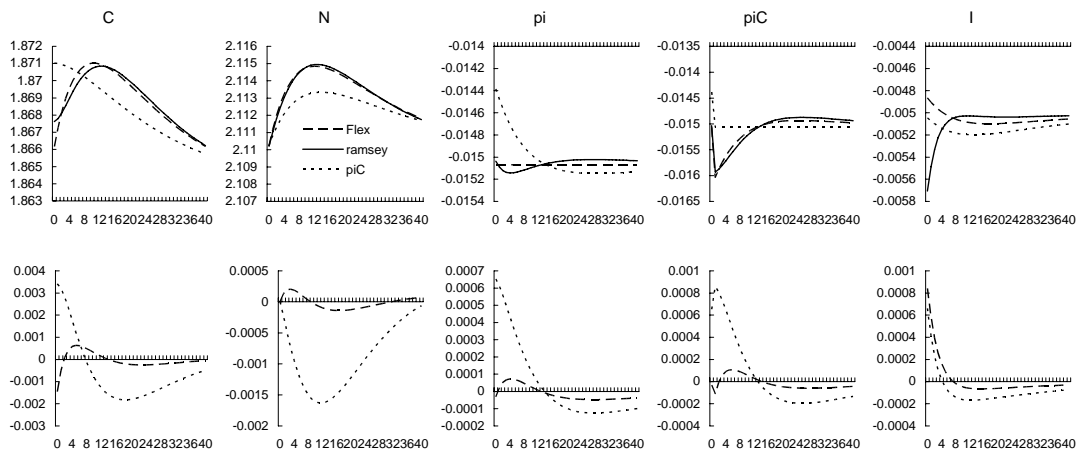


Figure 19: Productivity gain

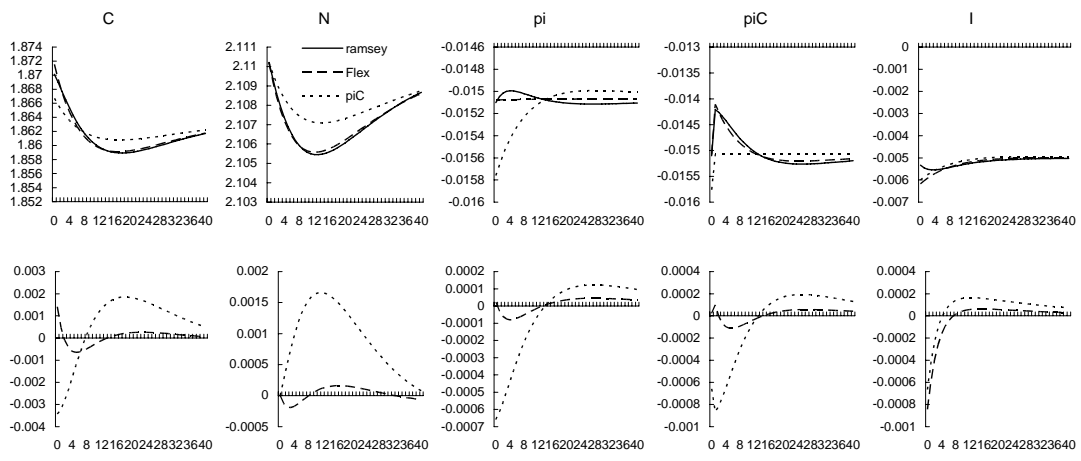


Figure 20: (Negative) Efficiency gain

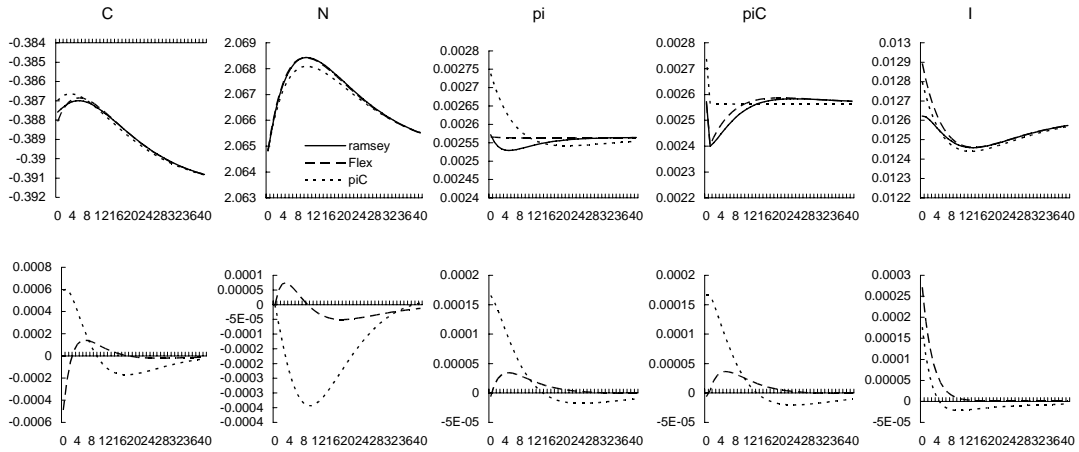


Figure 21: Productivity gain

Translog Figures 21 and 22 are responses under translog preference. Again, similar to the case with the CES preferences, flexible price allocations and prices are much more similar to those under the Ramsey policy planner. Yet, there may exist possible welfare gains from additionally referring to welfare-based inflation.

Results in these experiments under the Ramsey steady states suggest that the Ramsey policy is almost the same as the cross-sectional average inflation stabilization. Yet, central banks may be able to increase welfare by targeting the mixture of the cross-sectional average inflation and the welfare based inflation rate. Although the welfare-based inflation stabilization does not necessarily imply the control of the optimal number of firms, monetary policy referring also to the welfare-based inflation can, however, increase welfare through incomplete stabilization. Inflation rates as a tax can be used by the Ramsey policy planner, as a tool to control the number of firms so that the economy becomes closer to the Pareto optimal situation. Therefore, lack of stabilization of the cross-sectional average inflation may result in

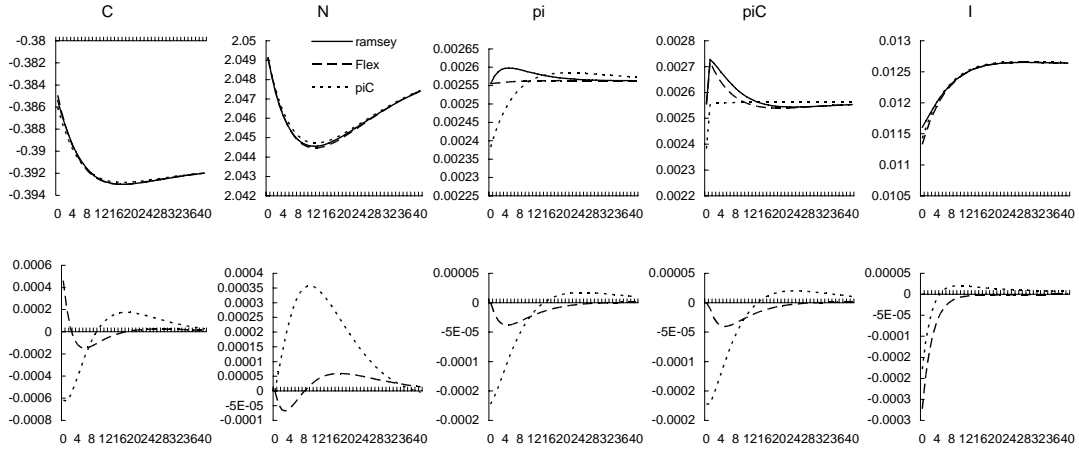


Figure 22: (Negative) Efficiency gain

higher welfare. Overall, however, we see that such gains should be very small. As the weight on the firm dynamics in welfare-based inflation as shown in (54) becomes smaller with larger θ , the usefulness of the welfare-based inflation targeting could become larger when the goods are very much substitutable. This is quite natural but at the same time very ironic result, since with higher θ , the welfare-based inflation targeting becomes closer to the cross-sectional average inflation targeting.

3.6 Conclusion

In this paper, we re-think price stability in an economy with endogenous firm entry. The contributions of this paper are summarized as follows.

We first demonstrate that the endogenous entry causes real imperfections introduced in Blanchard and Galí (2007). Reflecting fluctuations in the number of varieties, the gap between the natural and the efficient level of output is no longer constant and variant to shocks. As a result, central banks face a trade-off between

stabilizing inflation and the welfare-relevant output gap. Then, we show that this results in the non-zero optimal rate of inflation. We further examine whether the welfare can be enhanced by targeting the welfare-based inflation instead of the cross-sectional average inflation contrary to the findings in Bergin and Corsetti (2005) and Bilbiie et al. (2007), in two cases, namely when the natural rate of interest is unknown and the non-stochastic steady states are distorted. Simulations even with such distortions as unknown natural rate or no fiscal remedy for efficient non-stochastic steady states, however, support the cross-sectional average inflation targeting. Although incomplete stabilization enhances welfare in an economy when agents cannot internalize the externality on the love for variety, there only exists small gains by referring also to the welfare-based inflation.

Future direction is to extend this research by endogenizing the firm destruction as examined in Melitz (2003) and Ghironi and Melitz (2005).⁵⁵ As less productive firms exit from the market, monetary policy may be able to control the aggregate productivity by controlling the number of firms via inflation rates. Monetary policy can have direct effects on aggregate technology. In a discussion on Levin et al. (2005), it is written that “Justin Wolfers wondered about the possibility of monetary policy having long-run effects. Specifically, he noted that if the natural rate of unemployment is itself a function of policy, there could be deep welfare costs.” Furthermore, Kocherlakota (2007) demonstrates, by using the optimal tax problem under non-testable assumption about how stochastic shock to the labor-supply curve co-vary

⁵⁵This extension could result in much more volatile movements in flexible price equilibrium. Therefore, the trade-off could be more evident.

with tax rates, that “a model that fits the available data perfectly may provide worse answers to policy questions than an alternative” and “this kind of estimation is only useful if we have reliable *a priori* evidence about the shock process.” Analyses on monetary policy under models with endogenous exit may bring us very interesting implications concerning on the relationship between monetary policy and technology as above arguments suggest.

4 Growth Expectation

4.1 Introduction

For a long time, changes in expectations about the future have been thought to be significant sources of economic fluctuations. For example, Pigou (1926) states that “while recognizing that the varying expectations of business men may themselves be in part a psychological reflex of good and bad harvests – while not, indeed, for the present inquiring how these varying expectations themselves come about – we conclude definitely that they, and not anything else, constitute the immediate cause and direct causes or antecedents of industrial fluctuations.” It has, however, been considered a difficult challenge to create such an expectation-driven cycle, namely the “Pigou cycle”⁵⁶ in equilibrium business cycle models. Barro and King (1984) point out that “With a simple one-capital-good technology, no combination of income effects and shifts to the perceived profitability of investment will yield positive comovements of output, employment, investment and consumption.” Only recently have several researchers succeeded in generating the Pigou cycle by balancing the tension between the wealth effect and the substitution effect stemming from higher expected future productivity. The pioneering work of Beaudry and Portier (2004) was the first to generate the Pigou cycle in an equilibrium business cycle model. By introducing the multi-sectoral adjustment costs, the complementarity between consumption and investment is intensified so that consumption, labor and investment exhibit comovements reflecting forecast errors. Jaimovich and Rebelo (2006) reduce

⁵⁶We follow the terminology used by Beaudry and Portier (2004).

the wealth effect from the news shock by employing Greenwood et al. (1988)–type preferences.⁵⁷ They also increase the substitution effect by introducing investment growth adjustment costs,⁵⁸ which were first introduced by Christiano et al. (2005). They do so in order to generate expectation–driven business cycle. Denhaan and Kaltenbrunner (2007) use the labor search and matching framework to show that matching frictions offset reduced labor supply reflecting the wealth effect. Because high expected productivity induces firms to post more vacancies, both consumption and investment increase in response to positive news about future productivity. Kobayashi, Nakajima and Inaba (2007) demonstrate that the Pigou cycle can emerge in a model that incorporates collateral constraints. Good news raises the current price of land, which relaxes the collateral constraint and reduces the inefficiency in the labor market. If this effect is sufficiently strong, equilibrium labor supply increases, as do output, investment and consumption. Beaudry, Collard and Portier (2006) focus on the extensive margin of efficiency, namely technological progress in the form of the number of newly introduced goods. Anticipation of the arrival of new goods does not have any wealth effect but does induce investment, which is needed for the production of such new goods. This creates what authors term “Gold Rush Fever.”

Christiano, Ilut, Motto and Rostagno (2007, henceforth CIMR) is of particular interest. First, their work is based on the *de facto* standard macroeconomic model used by policy making institutions such as central banks. Currently, many central

⁵⁷They further assume time–non–separable preferences.

⁵⁸For the foundations of investment growth adjustment costs, see Lucca (2007).

banks construct their core macroeconomic models by following the influential work of Christiano et al. (2005).⁵⁹ These models have sufficiently rich dynamics to explain the trend apparent in data by incorporating investment growth adjustment costs, habit formation in consumption, sticky prices and wages, and an inflation–targeting central bank. We know the empirically plausible range of parameter values for this type of model. Second, the CIMR can explain not only comovements in consumption, employment and investment, but also “stock market boom–bust cycles,” characterized by increases in stock prices relating to high expected levels of future technology. This is a useful contribution because it implies that strict inflation targeting, which is the benchmark principle in the implementation of modern monetary policy, risks generating bubbles.

The research cited has deepened our understanding of the effects of expectations about future events on current variables. The associated models, however, incorporate rather unrealistic expectations about the future. That is, they make assumptions about expectations of the future technology level, not the growth rate.⁶⁰ In the above studies, if a positive technology shock is anticipated for the subsequent year, then the technology growth rate is expected to decrease from that year onwards. The anticipation of a negative growth rate following a positive level technology shock seems unrealistic.⁶¹ For example, professional forecasters usually predict a higher growth

⁵⁹See, for example, Adolfson et al. (2007), Erceg et al. (2006), Smets and Wouters (2003) and Laxton and Pesenti (2003).

⁶⁰The assumption about technological process made by Denhaan and Kaltenbrunner (2007) can be considered a combined assumption about the growth rate and the level of technology.

⁶¹With a positive deterministic trend technology growth, the growth rate will not become nega-

rate, rather than a higher level following news about future technological progress.⁶² Therefore, in this paper, we also examine the effect of people temporarily anticipate the higher technology growth rate by using the model employed by CIMR; for this model, empirically reasonable ranges of parameter values are readily available.⁶³ Indeed, in their seminal research, Beaudry and Portier (2006), who use a structural VAR with long-run restrictions to identify a news shock as one that affects the stock price but has no permanent effects on labor productivity, assume an expectation shock relating to a higher future growth rate of technology. It is shown that such an expectation-driven cycle is difficult to generate under the assumption of “growth expectation,” under which there is an expectation of a higher productivity growth rate. Thus, the Barro and King (1984) conjecture still applies.

This paper is structured as follows. In Section 2, we briefly describe the model and state the assumption made about technological process. Then, in Section 3, we present simulation results for growth expectation. We summarize our findings in

tive.

⁶²This is connected to the argument in time-series analyses about whether the time trend is stochastic or deterministic with stationary shocks around it causing variables to fluctuate.

⁶³In addition to the time-series arguments, recently, it has become more common to assume a shock to the growth rate rather than to the level. For example, in order to explain the realistic size of the premium, Bansal and Yaron (2004) introduce the concept of “Long Run Risk.” Aguiar and Gopinath (2007) show that business cycles in the emerging economies are better explained by trend shocks than by level shocks. Furthermore, the IS shock in the standard dynamic new Keynesian model, which is usefully summarized by Walsh (2003) and Woodford (2003) can be considered a growth rate shock to technology.

Section 4.

4.2 The Model

Because our model is similar to that of CIMR, we relegate the detailed derivations of the model, detrending and log-linearization to the appendix. In this section, we focus on explaining the shock process and how expectation shocks are simulated.⁶⁴

The model incorporates continuum of households and firms each within the unit mass, a central bank and a fiscal authority. The monopolistically competitive equilibrium in this paper is determined as follows. Households determine optimally the demand for goods, the supply of capital and the supply of labor in a monopolistically competitive labor market by choosing the desired wage subject to a Rotemberg (1982)-type adjustment cost.⁶⁵ Firms choose the amount of goods to supply by setting the desired price in a monopolistically competitive market subject to the Rotemberg-type adjustment cost. Firms also optimally choose labor demand and the capital stock. The central bank sets nominal interest rates by following the Taylor (1993)-type rule. The fiscal authority from households the lump-sum tax, which funds the subsidies that enable households to avoid undersupplies of labor and goods.

⁶⁴The Matlab code for the simulations used in this paper are available upon request. Fujiwara and Kang (2006) provides a tool for using Dynare for expectation shocks.

⁶⁵We use the Rotemberg-type cost instead of a Calvo (1983)-type staggered price settings because of its analytical tractability, and also because, when using Calvo pricing, one must assume indexation with possible trend growth. For the latter, see CIMR and Schmitt-Grohé and Uribe (2006).

4.2.1 Shock Process

The notable feature of the model used in this paper is the assumption about technological progress. Simulations are conducted based on the standard technology level shock as well as the technology growth rate shock, represented by the stochastic trend. For the latter, we assume that the trend technology follows the process described below:

$$Z_t = \mu \exp(u_t) Z_{t-1}, \quad (82)$$

where Z is the trend technology, u is the technology growth shock, and μ is the average growth rate of technology. The technology growth rate shock is further assumed to follow an AR (1) process:

$$u_t = \rho_u u_{t-1} + \chi_{u,t-p} + \varepsilon_{u,t},$$

where χ denotes an expectation shock, which, at period t , is anticipated to occur at period p . Because we do not assume any population growth in this paper, such variables as output, consumption and capital are denominated by this trend technology. Hence, the model produces a stationary rational expectation equilibrium, details of which are shown in the appendix. The standard technology level shock z appears in the production function for firm j as follows:

$$Y_{j,t} = [Z_t \exp(z_t) h_{j,t}]^{1-\alpha} K_{j,t}^\alpha,$$

where Y is the output, h is hours worked, K is the capital stock, and α is the labor share. This technology level shock is also assumed to follow an AR (1) process:

$$z_t = \rho_z z_{t-1} + \chi_{z,t-p} + \varepsilon_{z,t}. \quad (83)$$

4.2.2 Expectation Shock

To show how to incorporate an expectation shock, we first explain the general solution of the rational expectation model. A rational expectation model can be represented as follows:⁶⁶

$$\overline{\alpha_0} \mathbf{E}_t \widehat{z}_{t+1} + \overline{\alpha_1} \widehat{z}_t + \overline{\alpha_2} \widehat{z}_{t-1} + \overline{\beta_0} \mathbf{E}_t s_{t+1} + \overline{\beta_1} s_t = 0, \quad (84)$$

and

$$s_t = \overline{P} s_{t-1} + \varepsilon_t. \quad (85)$$

where variables with overlines are matrices of coefficients, \widehat{z} is the vector of endogenous variables and s is the vector of shocks. The solution that we want to obtain is

$$\widehat{z}_t = \overline{A} \widehat{z}_{t-1} + \overline{B} s_t. \quad (86)$$

By substituting, equations (85) and (86) into (84), we obtain

$$\overline{\alpha_0} \overline{A}^2 + \overline{\alpha_1} \overline{A} + \overline{\alpha_2} = 0, \quad (87)$$

and, if there exist only trivial solutions,

$$(\overline{\beta_0} + \overline{\alpha_0} \overline{B}) \overline{P} + (\overline{\beta_1} + \overline{\alpha_1} \overline{B} + \overline{\alpha_0} \overline{A} \overline{B}) = 0. \quad (88)$$

Matrix \overline{A} and \overline{B} in the solutions to equations (85) and (86) are computed by solving the equations (87) and (88). Whether we can obtain a unique \overline{A} depends on the standard Blanchard and Kahn (1980) condition.

Simulations of expectation shocks can be conducted by making adjustments to $\overline{\beta_0}$ and $\overline{\beta_1}$, in which case, we can obtain a new \overline{B} matrix. For simplicity, we consider

⁶⁶For the most part, we follow Christiano (2002).

the case in which there is only a standard technology level shock z in equation (83).

As a simple example, suppose that we receive news that “productivity is raised in period 2” (that is, currently, $p=2$), but that, come period 2, this news turns out to be false.⁶⁷ The above equation is represented in canonical form as follows:

$$\begin{pmatrix} z_t \\ \chi_{z,t} \\ \chi_{z,t-1} \end{pmatrix} = \begin{pmatrix} \rho_z & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} z_{t-1} \\ \chi_{z,t-1} \\ 0 \end{pmatrix} + \begin{pmatrix} \varepsilon_{z,t} \\ \chi_{z,t} \\ 0 \end{pmatrix}. \quad (89)$$

Adding a news shock $\chi_{z,0}$ at period 0 yields

$$\begin{pmatrix} z_0 \\ \chi_{z,0} \\ \chi_{z,-1} \end{pmatrix} = \begin{pmatrix} \rho_z & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} z_{-1} \\ \chi_{z,-1} \\ \chi_{z,-2} \end{pmatrix} + \begin{pmatrix} 0 \\ \chi_{z,0} \\ 0 \end{pmatrix}.$$

Although $\chi_{z,0}$ does not affect z_0 or $E_0 z_1$, the shock to technology at period 2 that is expected in period 0 becomes

$$E_0 \begin{pmatrix} z_2 \\ \chi_{z,2} \\ \chi_{z,1} \end{pmatrix} = \begin{pmatrix} \rho^2 & 1 & \rho \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} z_0 \\ \chi_{z,0} \\ \chi_{z,-1} \end{pmatrix}.$$

Hence, we have

$$E_0 z_2 = \chi_{z,0},$$

since

$$z_0 = \chi_{z,-1} = 0.$$

⁶⁷In the simulations below, we also report results for the case in which the initial guess comes true.

Therefore, the shock to technology at period 2 that is expected in period 0 becomes $\chi_{z,0}$. If such expectations materialize, then the simulation is conducted by using the appropriate s vector and $\overline{\beta}_0^*$, $\overline{\beta}_1^*$ and \overline{B}^* as defined below. When period 2 comes, however, such a positive shock does not occur. This is because $\chi_{z,0}$ is offset by χ_2 because $\chi_2 = -\varepsilon_0$. These notations are represented by

$$\begin{pmatrix} z_2 \\ \chi_{z,2} \\ \chi_{z,1} \end{pmatrix} = \begin{pmatrix} \rho_z & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} z_1 \\ \chi_{z,1} \\ \chi_{z,0} \end{pmatrix} + \begin{pmatrix} \varepsilon_{z,2} \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}.$$

Thus, although we can generate shocks as at period 0 and 1 such that a technology shock is expected at period 2, it turns out that there is a bubble expectation in period 2.

The canonical form of the shock process continues to be represented by equation (85). We must, however, construct a new shock vector s^* that incorporates an expectation shock term $\chi_{z,t}$ as follows:

$$s_t^* = \begin{pmatrix} z_t \\ \chi_{z,t} \\ \chi_{z,t-1} \end{pmatrix}.$$

We obtain a new $\overline{\beta}_0^*$ and $\overline{\beta}_1^*$ from the original $\overline{\beta}_0$ and $\overline{\beta}_1$ by adding zero vectors to the columns corresponding to $\chi_{z,t}$ in S . We can write the new \overline{P}^* as

$$\overline{\beta}_0^* = \begin{pmatrix} 0 & 0 \\ \beta_0 & 0 & 0 \\ 0 & 0 \end{pmatrix},$$

$$\overline{\beta}_1^* = \begin{pmatrix} 0 & 0 \\ \beta_1 & 0 & 0 \\ 0 & 0 \end{pmatrix},$$

and

$$\overline{P}^* = \begin{pmatrix} \rho_z & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}.$$

Then, we compute a new \overline{B}^* matrix from equation (88) by using Christiano (2002).

Thus, impulse responses under an expectation shock are produced by using equations (85) and (86).

4.3 Simulation Results

First, we examine the case in which there is no nominal rigidity, as is the case with the real model. Then, we examine the case in which there are price and wage rigidities; this case generates a stock market boom–bust cycle.

4.3.1 Real Model

As explained in the introduction, in the standard real business cycle model, comovements in consumption, investment and labor hours cannot be generated by a news shock to future technology. This is because expectations about future new technologies increases the real rate of return and generate wealth effects. Therefore, if the wealth effect outweighs the effect of the increased real rate of return, consumption and leisure increase. However, as labor hours decrease, output declines. At the same

time, investment is reduced because consumption increases and output decreases. If effect on the expected real rate of return dominates—that is, if the substitution effect outweighs the wealth effect—investment and labor hours increase. Because productivity has not yet increased, output growth is smaller than that in investment. Therefore, consumption falls. Thus, in each case, we cannot have positive comovements in consumption, investment and labor supply.

CIMR can generate positive comovements in consumption, investment and hours worked from a news shock about future productivity improvements by incorporating the investment intertemporal adjustment costs and habit formation in consumption. These are realistic assumptions that are commonly used in dynamic general equilibrium modeling of policy experiments by central banks. Intuitively, CIMR first try to generate increased labor supply by introducing investment growth adjustment costs through an increased substitution effect, and then they appropriately allocate the additional output that derives from the increased labor supply between consumption and investment.

4.3.2 Level Shock

We first reproduce CIMR’s investigation. The shock process anticipated by economic agents is illustrated Figure 23. A positive one percent technology level shock is expected to occur at period 4. Because this level shock is assumed to follow an AR(1) process, the expected growth rate has a spike at period 4 but it is expected to be negative thereafter as the level shock decays.

The impulse responses for the shock described above are illustrated in Figure 24.

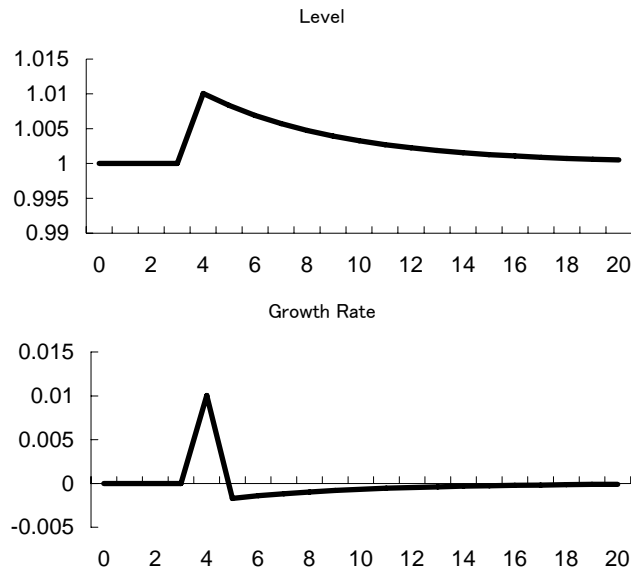


Figure 23: Level Shock Process

As CIMR found, hours worked, consumption and investment increase for an expected positive technology level shock.

4.3.3 Growth Shock

It is assumed that agents anticipate a growth rate shock process, as illustrated in Figure 25. In this case, although it is assumed that growth will eventually cease, it is anticipated that technology will not return to its previous level. Hence, the wealth effect is more prevalent in this shock scenario than before.

Figure 26 shows the impulse responses for such a growth rate shock. Because this figure shows the responses of the detrended variables, variables such as consumption and investment should be multiplied by the trend technology when the anticipated shock occurs. Yet, because we are interested in the case in which the anticipated

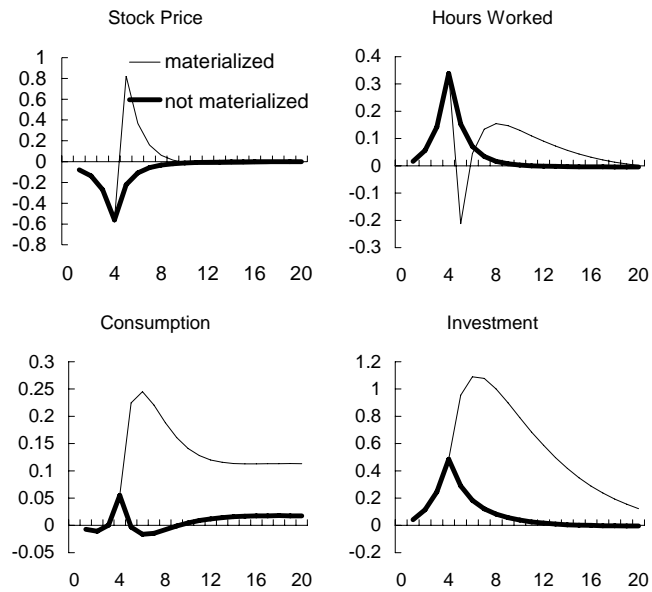


Figure 24: Level Shock: Real Model

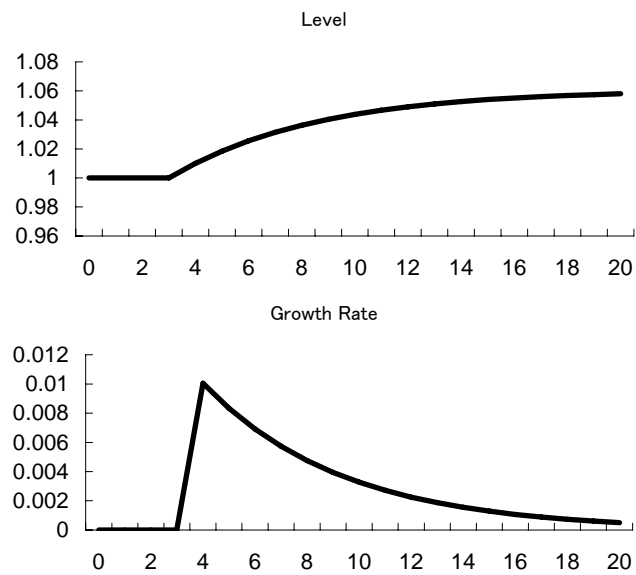


Figure 25: Growth Shock Process

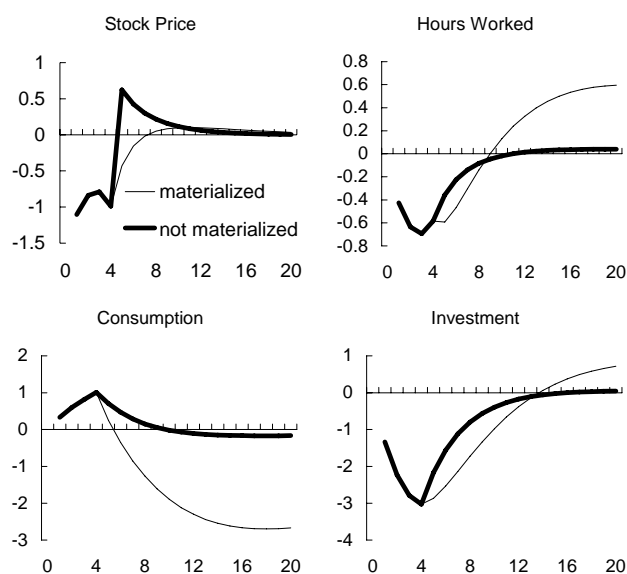


Figure 26: Growth Shock: Real Model

shock fails to materialize, we can ignore the trending problem as there is no change in the trend growth rate. Analyzing the case in which the shock actually occurs enables our understanding of the rational expectations formed by agents when they receive the signal. As expected from the strong wealth effect implied by the shock process illustrated in Figure 25, consumption and leisure increase.⁶⁸ Consequently, labor input and investment are reduced. To generate increased substitution effects, which operate through increased rates of return, we examine the case in which there are extremely high investment adjustment costs (larger than those in the baseline case by a factor 1,000).

Impulse responses in this model are shown in Figure 27. Even with such extremely

⁶⁸Consumption and leisure increase even under very high parameter for habit formation. Further increase in the parameter for habit formation does not change the results qualitatively.

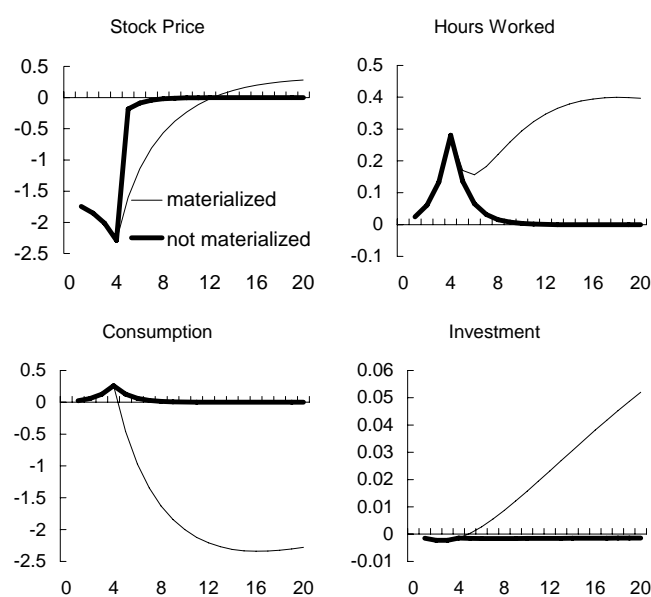


Figure 27: Growth Shock: Real Model with Very High S''

high adjustment costs, we cannot produce an increase in investment. To reduce the strength of the wealth effect, rather than use the persistent growth rate shock assumed in previous exercises, we further examine the case in which there is a one-off anticipated permanent increase in the level of technology, as shown in Figure 28, when there are extremely high investment adjustment costs (larger than those in the baseline case by a factor of 1,000). Impulse responses for this case are illustrated in Figure 29. The decreased wealth effect and the increased substitution effect from higher adjustment costs generate comovements in hours worked, consumption and investment. The most significant finding of the exercises so far is, however, that comovements only occur for parameter values that are unrealistic given the estimated obtained from the so-called canonical dynamic general equilibrium models based on Christiano et al. (2005).

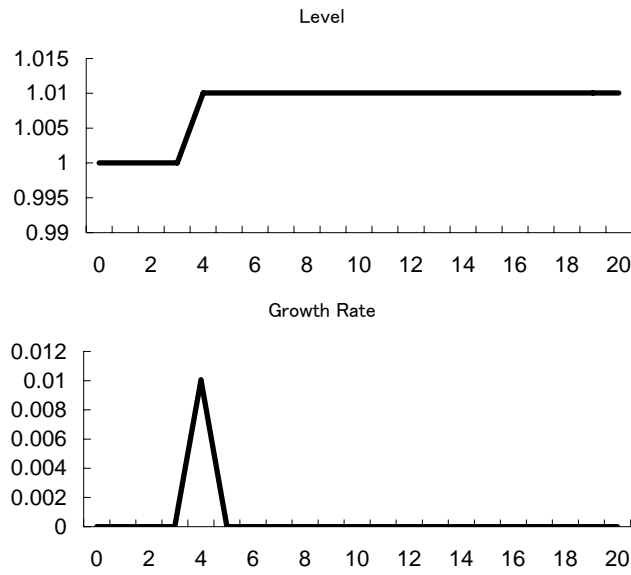


Figure 28: Growth Shock Process (no persistence)

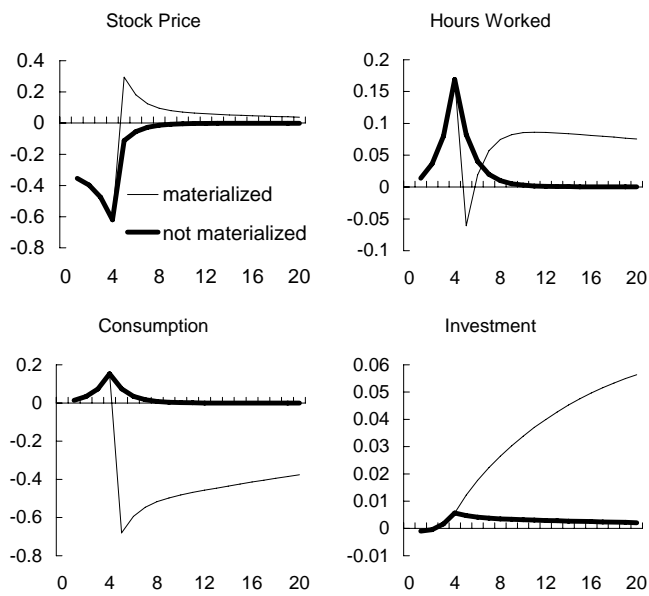


Figure 29: Growth Shock: Real Model with Very High S'' and $\rho_u = 0$

4.3.4 Extended Model with Nominal Rigidities

Although we generated positive comovements in consumption, investment and working hours for a positive news shock to new technology, the theoretical stock price decreases. This seems counter-intuitive, but it can be explained examining the following capital demand and capital supply equations:

$$P_{K',t} = \sum_{i=1}^{\infty} E_t \prod_{j=1}^i \frac{\pi_{t+j}}{R_{t+j-1}^n} (1-\delta)^{i-1} \alpha \phi_t [Z_t \exp(z_t)]^{1-\alpha} h_t^{1-\alpha} K_t^{\alpha-1}, \quad (90)$$

$$P_{K',t} = \frac{1}{1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right) \frac{I_t}{I_{t-1}}} - \frac{E_t \pi_{t+1}}{R_t^n} \frac{P_{K',t+1} S'\left(\frac{I_{t+1}}{I_t}\right) \frac{I_{t+1}^2}{I_t^2}}{1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right) \frac{I_t}{I_{t-1}}}. \quad (91)$$

Equation (90) is interpreted as the capital demand function, according to which households equate the theoretical price of capital to the present discounted value of future dividends. Equation (91) is the capital supply function. Capital producers choose the price of capital, represented by the left-hand side, based on the marginal cost of producing a unit of capital, which is represented by the right-hand side.⁶⁹ Figure 30, which illustrates the relationship between equations (90) and (91), clarifies the dynamic transition of the theoretical capital price from period 0 to period 1. Economy is at $P_{K',0}$ initially. Following the receipt of a positive news shock about future technology, the capital demand curve shifts upwards because of the expected increase in dividends; see panel (i). This upward shift of the demand curve is, however, mitigated by an increase in real interest rates, which are determined by the intertemporal ratio of the marginal utility from consumption, as shown by panel (ii).

⁶⁹To be precise, the role of capital producers is played by households in this model. Having capital producers who are separate from households would, however, make no difference to the analysis.

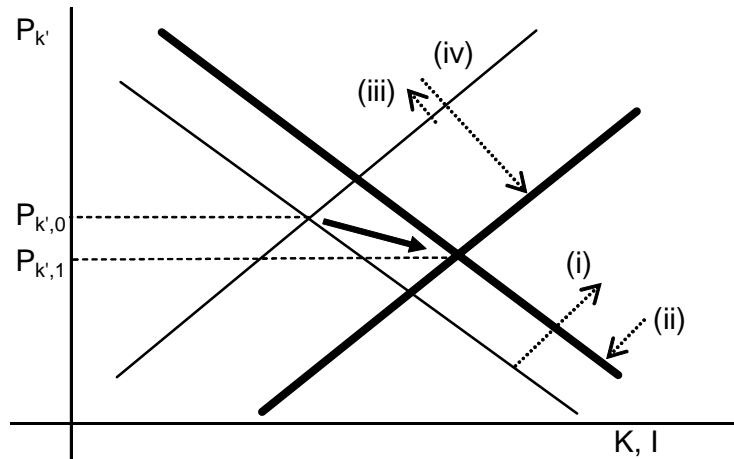


Figure 30: Capital Equilibrium

Concerning supply-side developments, increase in investment caused by the positive news shock raises marginal cost contemporaneously, as in panel (iii); this effect is represented by the first term on the right-hand side of equation (91). An increase in current investment, however, reduces the adjustment costs incurred because of higher investment growth in the future. This is represented by the second term in equation (91). Therefore, as shown in panel (iv), even though investment in period 1 increases, the capital supply curve shifts downwards. In the aggregate, given these demand and supply conditions, the theoretical stock price falls from $P_{K',0}$ to $P_{K',1}$ following a positive expectation shock to productivity. To explain a stock price bubble in this setting, CIMR incorporate both sticky prices and wages.⁷⁰

⁷⁰In particular, the sticky wage mechanism, introduced by Erceg et al. (2000), has direct effects on the Pigou cycle. Barro and King (1984) state that “We should stress the result that consumption and leisure end up moving in the same direction. We always get this result if (i) utility is separable over time, (ii) consumption and leisure are superior goods, and (iii) the current schedule for labor’s marginal product does not shift. Changes in prospective conditions end up affecting household’s

CIMR also adopt the Taylor (1993)–type instrument rule.⁷¹ A positive news shock to future productivity implies that future marginal costs will be lower. If price setting is mainly forward looking (that is, incorporates little indexation and imposes few barriers to the acquisition of new information), then the current inflation rate is lower. Hence, according to the Taylor–type instrument rule, under which there are aggressive reactions to inflation developments, nominal as well as real interest rates are lowered. This shifts the capital demand curve in Figure 30 outwards. As a result, according to CIMR, a stock price boom can occur after an expectation shock hits the economy.

Level Shock For the model with nominal rigidities, Figure 31 below shows the responses for the technology level shock, as did Figure 24 for the real model. As stated above, the introduction of nominal rigidities and an inflation–targeting central bank leads lower nominal interest rates, reflecting better future technology, through a lower inflation rate, to contribute to increasing the stock price. Furthermore, reduced interest rates and the wage changes, which reflect an increase in the future marginal

total current real expenditure on consumption and leisure. Given time–separable utility, this change amounts solely to an income effect, which moves consumption and leisure in the same direction if both goods are superior. Thus, the two goods can move in opposite directions only if there is a shift in the (schedule for the) current relative price, which is the real wage rate. But we rule this out by assuming no shift in the schedule for labor’s current marginal product.” The sticky wage mechanism can alter the real wage rate to reflect future technological improvements.

⁷¹As shown in the appendix, CIMR assumes a forward–looking Taylor–type rule. This also helps to generate stock market boom–bust cycles.

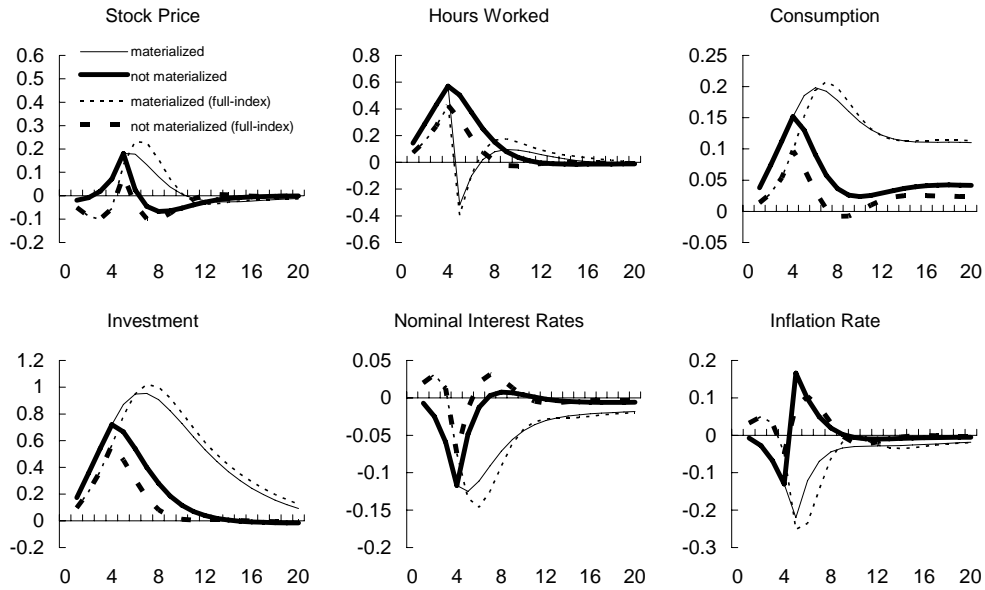


Figure 31: Level Shock: New Keynesian Model

product of labor through the sticky wage mechanism, make comovements in hours worked, consumption and investment more evident. The sticky wage mechanism alters the trade-off between consumption and leisure. Because the response of current inflation to expected events is crucial in generating the stock market boom-bust cycle, when prices as well as wages are not indexed, the boom-bust cycle is more evident.

The response of the stock price is minimal. The size of the response seems to be magnified by having more persistent expectations of future technology growth. Next, we show that this simply generates outcomes that are less realistic.

Growth Shock Similarly to Figure 26, Figure 32 illustrates impulse responses for the expected growth rate shock. Similarly to the case of the real model, in this model, we cannot produce comovements in stock prices, hours worked, consumption

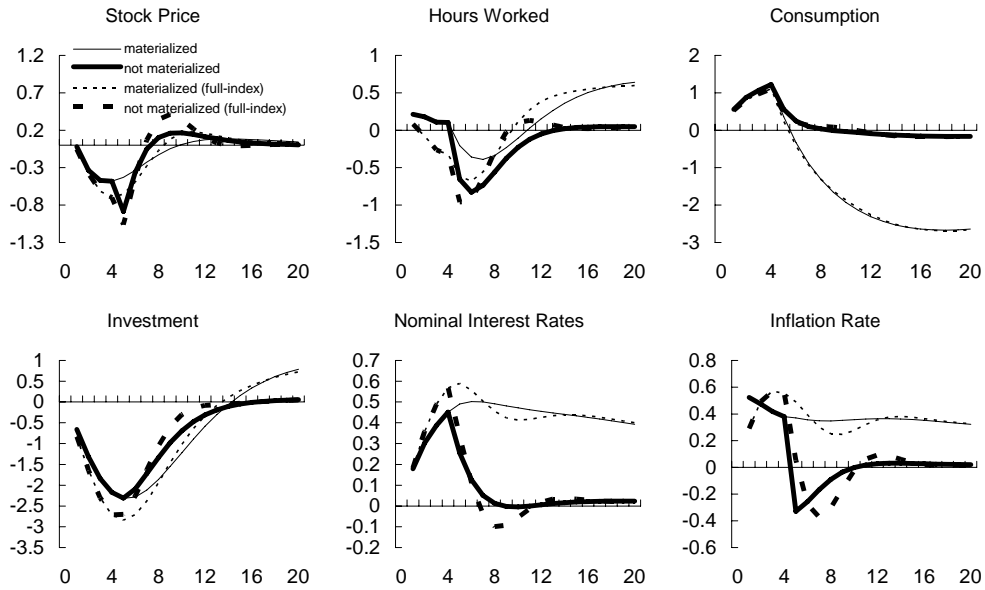


Figure 32: Growth Shock: New Keynesian Model

and investment. This is because of the strong wealth effect in this economy. Unlike in the case with of real model illustrated in Figure 26, however, in this model, hours worked increases. This is consistent with the finding of Barro and King (1984) that “Thus, the two goods can move in opposite directions only if there is a shift in the (schedule for the) current relative price, which is the real wage rate.” Because of the sticky wage mechanism, the real wage rate changes to reflect the increase in the future marginal product of labor. This raises current real wages and makes leisure more expensive. The divergence of labor and investment is exacerbated by monetary tightening, which reflects the increase in the inflation rate following the receipt of positive news about the future productivity growth rate. We revisit this issue in the next exercise.

Similarly to Figure 29, Figure 33 shows the responses following a permanent

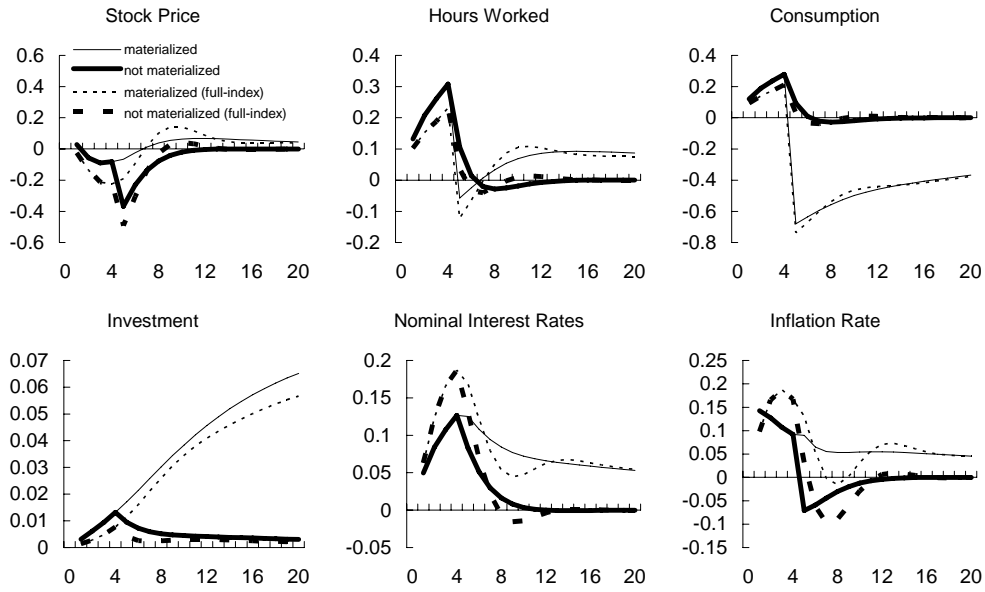


Figure 33: Growth Shock: New Keynesian Model with very high S^m and $\rho_u = 0$

increase in the technology level shock, when investment intertemporal adjustment costs are extremely high (100 larger than those in the baseline model). Because of the high investment growth adjustment costs and the reduced wealth effect, comovements in hours worked, consumption and investment are possible. Detrended consumption declines substantially following the confirmation that the news is true because investment must increase substantially.

Nevertheless, even if investment growth adjustment costs increase and the wealth effect is reduced, there will be no stock market boom in this case. As explained above, this is because inflation rates are higher under growth expectation than when a technology level shock is expected. This is explained below. It is clear from thin lines in Figures 32 and 33, that investment must eventually increase following the permanent positive change in productivity. When investment growth adjustment

costs are high, agents try to increase investment as soon as they receive the signal. Yet, because agents know that they will be rich in the future, they would like to consume more and have more leisure through the wealth effect. To mitigate these two motives, that is, by increasing both consumption and investment, agents need to work more hours although they prefer leisure to work. These developments raise the current marginal cost and therefore inflation rates. Thus, both nominal interest rates and eventually real interest rates are raised by the central bank following its Taylor-type instrument rule.⁷² By contrast, CIMR predict deflation, low interest rates and an asset price boom, which is more consistent with the data during an asset price boom.⁷³

⁷²This is similar to the predictions of the canonical new Keynesian model. The output gap, measured as the deviation from the output at the flexible price equilibrium, increases according to the Euler equation when there is a shock to the technology growth rate but decreases when there is a shock to the level of technology.

⁷³If we alter the forecast horizon of the news shock, the very short-living expectation-driven business cycle can materialize with small persistence in the growth rate shock. This is because by shortening the forecast horizon, the substitution effect to increase the current capital to prepare for the future increase in the technology becomes stronger, that is, the news shock becomes closer to the contemporaneous shock. Yet, inflation rates becomes higher initially, that is not very much consistent with the data. For the analysis on the forecast horizon of the news shocks, see Fujiwara, Hirose and Shintani (2008b).

4.4 Conclusion

In this paper, we showed that it is difficult to produce the Pigou cycle, which is characterized by comovements in hours worked, consumption and investment, in equilibrium business cycle models that incorporate growth expectation. We found that empirically implausible values for some parameters are required to generate the Pigou cycle under growth expectation. Furthermore, we found that generating a stock market boom–bust cycle, which is a Pigou cycle augmented by a positive reaction of the stock price, is even more difficult. Even if one uses empirically implausible parameters, it is virtually impossible to get the stock price to react positively to news of higher future productivity growth. Labor inputs must be increased in the face of a substantial wealth effect to meet the demand for investment subject to the adjustment costs. This results in higher inflation and, thereby, through the operations of the inflation–targeting central bank, higher real interest rates. The key mechanism used by CIMR to generate a stock market boom–bust cycle is an outward shift of the capital demand curve following a fall in real interest rates. Under growth expectation, because of strong wealth effects, it seems inconceivable that, in the standard model, one could have both deflation and output growth without an expansion of the production frontier. Therefore, we conclude that Barro and King’s (1984) predictions continues to apply.

In future research, we aim to solve the problem of generating the Pigou cycle from growth expectation by considering the filtering problem in the context of the permanent components of news shocks, as examined by Edge, Laubach and Williams

(2007), and in the context of limited information about news shocks, as analyzed by Sims (2003) and Reis (2006).

Appendix: Model Derivation

The model consists of four agents, firms, consumers, the central bank and the fiscal authority.

Firms are assumed to face a cost minimization problem subject to a Rotemberg-type adjustment cost. The real marginal cost ϕ is derived from the cost minimization problem when each firm j minimizes its total cost subject to the production technology by choosing labor inputs h and the capital K , as follows:

$$\min_{h_{j,t}, K_{j,t}} \frac{W_t}{P_t} h_{j,t} + r_t^K K_{j,t},$$

subject to

$$Y_{j,t} = [Z_t \exp(z_t) h_{j,t}]^{1-\alpha} K_{j,t}^\alpha,$$

where W is the nominal wage, P is the price level and r^K is the cost of capital. Each firm sets its prices in order to maximize the real dividend D subject to the Rotemberg-type adjustment cost:

$$D_{j,t} = (1 + \tau) \frac{P_{j,t}}{P_t} Y_{j,t} - \phi_t Y_{j,t} - \frac{\zeta_p}{2} \left(\frac{P_{j,t}}{P_{j,t-1}} - 1 \right)^2 Y_t,$$

and the downward sloping demand curve stemming from the monopolistic competition:

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\theta_p} Y_t,$$

where ζ_p is the parameter for the Rotemberg-type adjustment cost, θ_p is the elasticity of substitution among differentiated goods, and τ is the production subsidy rate. As is clear from the equation that defines the real dividend, the steady state inflation rate is assumed to be zero.

Each household i supplies labor in a monopolistically competitive labor market and maximizes utility U :

$$U_{i,t} = \log(C_{i,t} - bC_{i,t-1}) - \psi_L \frac{h_{i,t}^{1+\sigma_L}}{1+\sigma_L},$$

where b is the parameter for habit formation, ψ_L determines the size of labor disutility and σ_L is the Frish elasticity of the labor substitution, subject to the budget constraint:⁷⁴

$$\begin{aligned} \frac{B_{i,t+1}}{P_t} = & R_{t+1}^n \frac{B_{i,t}}{P_t} + (1 + \tau_W) \frac{W_{i,t}}{P_t} h_{i,t} \left\{ 1 - \frac{\zeta_w}{2} \left[\frac{W_{i,t}}{\mu \exp(u_t) W_{i,t-1}} - 1 \right]^2 \right\} \\ & + r_t^K K_{i,t} + D_{i,t} - C_{i,t} - I_{i,t} - T_{i,t}, \end{aligned}$$

the capital formation equation, in which the depreciation rate is δ :

$$K_{i,t+1} = (1 - \delta)K_{i,t} + \left[1 - S \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] I_{i,t},$$

where the investment adjustment cost takes the form:

$$S \left(\frac{I_t}{I_{t-1}} \right) = S'' \left\{ \frac{\left(\frac{I_t}{I_{t-1}} \right)^2}{2} - \left(\frac{I_t}{I_{t-1}} \right) \mu \exp(u_t) + \frac{[\mu \exp(u_t)]^2}{2} \right\},$$

and the downward sloping labor demand stemming from the monopolistically competitive labor market:

$$h_{j,t} = \left(\frac{W_{j,t}}{W_t} \right)^{-\theta_h} h_t,$$

where B is the nominal debt,⁷⁵ R^n is the nominal interest rate, I is investment, T

⁷⁴We detrend variables by using equation (82). Therefore, both wage and investment adjustment costs are affected by the trend growth shock. The results do not change even we exclude the effects from the growth rate shock on adjustment costs.

⁷⁵Aggregate debt, namely B , is set to be zero.

is a lump-sum tax, τ_W is the labor subsidy rate, and ζ_w is the parameter for the Rotemberg-type adjustment cost.

The central bank sets short-term nominal interest rates by following a Taylor-type rule as follows:

$$R_{t+1}^n = \rho R_{t-1}^n + (1 - \rho) \left[R + \eta \left(\frac{E_t P_{t+1}}{P_t} - 1 \right) + \eta_y \left(\frac{Y_t}{Y_t^+} - 1 \right) \right],$$

where ρ controls the history dependency of monetary policy, η is the coefficient on inflation, η_y is that on the output gap and Y^+ is aggregate output on a non-stochastic steady-state growth path.⁷⁶ The forward-looking monetary policy rule on future inflation contributes to producing the Pigou cycle because nominal interest rates fall as the marginal cost is reduced because of expected higher productivity.

The fiscal authority simply collects the lump-sum tax from households and subsidizes monopolistically competitive firms and workers as follows:

$$\tau Y + \tau_W \frac{W}{P} h = \int_0^1 T_i di = T.$$

A Level Equations

From the first-order conditions and the resource constraint, we obtain a model in 12 level equations under the symmetric equilibrium,⁷⁷ in which the inflation rates is

$$\pi_t = \frac{P_t}{P_{t-1}},$$

⁷⁶Therefore, in this paper, the output gap is not the theoretical output gap measured as the deviation from output at the flexible price equilibrium.

⁷⁷Both firms and households are assumed to be within the unit mass.

and the theoretical value of the stock price $P_{K'}$ is the ratio of the Lagrange multiplier for capital formation to that on the budget constraint:

$$P_{K',t} = \frac{\mu_t}{\lambda_t}.$$

- (L1) $[Z_t \exp(z_t) h_t]^{1-\alpha} K_t^\alpha = C_t + I_t + \frac{\theta_w}{\theta_w - 1} \frac{W_t}{P_t} h_t \frac{\zeta_w}{2} \left[\frac{W_t}{\mu \exp(u_t) W_{t-1}} - 1 \right]^2$
 $+ \frac{\zeta_p}{2} (\pi_t - 1)^2 [Z_t \exp(z_t) h_t]^{1-\alpha} K_t^\alpha,$
- (L2) $K_{t+1} = (1 - \delta)K_t + \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) \right] I_t,$
- (L3) $\frac{1}{C_t - bC_{t-1}} - \lambda_t - bE_t \beta \frac{1}{C_{t+1} - bC_t} = 0,$
- (L4) $\frac{W_t}{P_t} = (1 - \alpha) \phi_t [Z_t \exp(z_t)]^{1-\alpha} h_t^{-\alpha} K_t^\alpha,$
- (L5) $\varphi_t - 1 + \frac{\zeta_w}{2} \left(\frac{W_t}{\mu \exp(u_t) W_{t-1}} - 1 \right)^2$
 $- \frac{\zeta_w}{\theta_h - 1} \left(\frac{W_t}{\mu \exp(u_t) W_{t-1}} - 1 \right) \frac{W_t}{\mu \exp(u_t) W_{t-1}}$
 $+ \beta \frac{\zeta_w}{\theta_h - 1} \left(\frac{W_{t+1}}{\mu \exp(u_{t+1}) W_t} - 1 \right) \left(\frac{W_{t+1}}{\mu \exp(u_{t+1}) W_t} \right)^2 \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{h_{t+1}}{h_t} = 0,$
- (L6) $\varphi_t = \frac{\psi_L h_t^{\sigma_L}}{\lambda_t \frac{W_t}{P_t}},$
- (L7) $r_t^K = \alpha \phi_t [Z_t \exp(z_t)]^{1-\alpha} h_t^{1-\alpha} K_t^{\alpha-1},$
- (L8) $P_{K',t} = \beta \frac{\lambda_{t+1}}{\lambda_t} E_t [r_{t+1}^K + P_{K',t+1}(1 - \delta)],$
- (L9) $-1 + P_{K',t} \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) \right] - P_{K',t} S'' \left[\frac{I_t}{I_{t-1}} - \mu \exp(u_t) \right] \frac{I_t}{I_{t-1}}$
 $+ \beta E_t P_{K',t+1} \frac{\lambda_{t+1}}{\lambda_t} S'' \left[\frac{I_{t+1}}{I_t} - \mu \exp(u_t) \right] \frac{I_{t+1}^2}{I_t^2} = 0,$
- (L10) $(1 - \theta_p) + \theta_p \phi_t - \zeta \left(\frac{P_t}{P_{t-1}} - 1 \right) \frac{P_t}{P_{t-1}}$
 $+ E_t \beta \frac{\lambda_{t+1}}{\lambda_t} \zeta_p \left(\frac{P_{t+1}}{P_t} - 1 \right) \frac{P_{t+1}}{P_t} \frac{[Z_{t+1} \exp(z_{t+1}) h_{t+1}]^{1-\alpha} K_{t+1}^\alpha}{[Z_t \exp(z_t) h_t]^{1-\alpha} K_t^\alpha} = 0,$
- (L11) $R_t^n = \rho R_{t-1}^n + (1 - \rho) \left\{ R + \eta E_t \pi_{t+1} + \eta_y \left\{ \frac{[Z_t \exp(z_t) h_t]^{1-\alpha} K_t^\alpha}{(Z_t h)^{1-\alpha} K^\alpha} - 1 \right\} \right\},$
- (L12) $-\frac{\lambda_t}{P_t R_t^n} + E_t \beta \frac{\lambda_{t+1}}{P_{t+1}} = 0.$

B Detrended Equations

To obtain the equilibrium conditions in terms of nongrowing variables only, we detrend variables by using equation (82) as follows:

$$c_t = \frac{C_t}{Z_t}, \quad i_t = \frac{I_t}{Z_t}, \quad k_t = \frac{K_t}{Z_{t-1}}, \quad \tilde{\lambda}_t = Z_t \lambda_t, \quad w_t = \frac{W_t}{P_t Z_t}, \quad \pi_t = \frac{P_t}{P_{t-1}}, \quad \text{and} \quad \pi_t^W = \frac{w_t}{w_{t-1}},$$

$$\begin{aligned}
(\text{DL1}) \quad & [\exp(z_t) h_t]^{1-\alpha} \left[\frac{k_t}{\mu \exp(u_t)} \right]^\alpha = c_t + i_t + \frac{\theta_W}{\theta_W - 1} w_t h_t \frac{\zeta_w}{2} \left(\frac{w_t}{w_{t-1}} \pi_t - 1 \right)^2 \\
& + \frac{\zeta_p}{2} (\pi_t - 1)^2 [\exp(z_t) h_t]^{1-\alpha} \left[\frac{k_t}{\mu \exp(u_t)} \right]^\alpha \\
(\text{DL2}) \quad & k_{t+1} = \frac{(1-\delta)k_t}{\mu \exp(u_t)} + \left\{ 1 - [\mu \exp(u_t)]^2 S'' \left[\frac{\left(\frac{i_t}{i_{t-1}}\right)^2}{2} - \frac{i_t}{i_{t-1}} + \frac{1}{2} \right] \right\} i_t, \\
(\text{DL3}) \quad & \frac{1}{c_t - \frac{bc_{t-1}}{\mu \exp(u_t)}} - \tilde{\lambda}_t - b \mathbf{E}_t \beta \frac{1}{c_{t+1} \mu \exp(u_{t+1}) - bc_t} = 0, \\
(\text{DL4}) \quad & w_t = (1 - \alpha) \phi_t [\exp(z_t)]^{1-\alpha} h_t^{-\alpha} \left[\frac{k_t}{\mu \exp(u_t)} \right]^\alpha, \\
(\text{DL5}) \quad & (1 - \theta_h) + \theta_h \varphi_t - (1 - \theta_h) \frac{\zeta_w}{2} (\pi_t^W \pi_t - 1)^2 \\
& - \zeta_w (\pi_t^W \pi_t - 1) \pi_t^W \pi_t \\
& + \beta \zeta_w (\pi_{t+1}^W \pi_{t+1} - 1) (\pi_{t+1}^W \pi_{t+1})^2 \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}} \frac{h_{t+1}}{h_t} = 0, \\
(\text{DL6}) \quad & \varphi_t = \frac{\psi_L h_t^{\sigma_L}}{\lambda_t w_t}, \\
(\text{DL7}) \quad & r_t^K = \alpha \phi_t [\exp(z_t)]^{1-\alpha} h_t^{1-\alpha} \left[\frac{k_t}{\mu \exp(u_t)} \right]^{\alpha-1}, \\
(\text{DL8}) \quad & P_{K',t} = \beta \frac{\tilde{\lambda}_{t+1}}{\mu \exp(u_{t+1}) \tilde{\lambda}_t} \mathbf{E}_t [r_{t+1}^K + P_{K',t+1} (1 - \delta)], \\
(\text{DL9}) \quad & -1 + P_{K',t} \left\{ 1 - [\mu \exp(u_t)]^2 S'' \left[\frac{\left(\frac{i_t}{i_{t-1}}\right)^2}{2} - \frac{i_t}{i_{t-1}} + \frac{1}{2} \right] \right\} \\
& - P_{K',t} [\mu \exp(u_t)]^2 S'' \left(\frac{i_t}{i_{t-1}} - 1 \right) \frac{i_t}{i_{t-1}} \\
& + \beta \mathbf{E}_t P_{K',t+1} \frac{\lambda_{t+1}}{\lambda_t} S'' \left(\frac{i_{t+1}}{i_t} - 1 \right) \left(\frac{i_{t+1}}{i_t} \right)^2 [\mu \exp(u_{t+1})]^2 = 0, \\
(\text{DL10}) \quad & (1 - \theta_p) + \theta_p \phi_t - \zeta (\pi_t - 1) \pi_t \\
& + \mathbf{E}_t \beta \frac{\tilde{\lambda}_{t+1}}{\lambda_t} \zeta_p (\pi_{t+1} - 1) \pi_{t+1} \frac{\exp(u_{t+1})}{\exp(u_t)} \left[\frac{\exp(z_{t+1}) h_{t+1}}{\exp(z_t) h_t} \right]^{1-\alpha} \left(\frac{k_{t+1}}{k_t} \right)^\alpha = 0, \\
(\text{DL11}) \quad & R_t^n = \rho R_{t-1}^n + (1 - \rho) \left\{ R + \eta \mathbf{E}_t \pi_{t+1} + \eta_y \left[\frac{\exp(z_t) h_t^{1-\alpha} k_t^\alpha}{h^{1-\alpha} k^\alpha} - 1 \right] \right\}, \\
(\text{DL12}) \quad & \frac{\mathbf{E}_t \pi_{t+1}}{R_t^n} = \mathbf{E}_t \beta \frac{\tilde{\lambda}_{t+1}}{\lambda_t \mu \exp(u_{t+1})}, \\
(\text{DL13}) \quad & \pi_t^W = \frac{w_t}{w_{t-1}}.
\end{aligned}$$

C Steady States

By eliminating the time subscript, we can obtain the non-stochastic steady states of 13 variables.

$$(SS1) \quad \pi = 1,$$

$$(SS2) \quad \pi^W = 1,$$

$$(SS3) \quad \phi = 1,$$

$$(SS4) \quad \varphi = 1,$$

$$(SS5) \quad \tilde{P}_{K'} = 1,$$

$$(SS6) \quad R = \frac{\mu}{\beta},$$

$$(SS7) \quad r^K = \frac{\mu}{\beta} - 1 + \delta,$$

$$(SS8) \quad w = (1 - \alpha) \left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right)^{\frac{\alpha}{\alpha-1}},$$

$$(SS9) \quad h = \left\{ \frac{\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) (1 - \alpha) (\mu - b\beta)}{\left[\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) - \mu + (1 - \delta) \right] \psi_L(\mu - b)} \right\}^{\frac{1}{\sigma_L + 1}},$$

$$(SS10) \quad k = \left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right)^{\frac{1}{\alpha-1}} \frac{1}{\mu} \left\{ \frac{\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) (1 - \alpha) (\mu - b\beta)}{\left[\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) - \mu + (1 - \delta) \right] \psi_L(\mu - b)} \right\}^{\frac{1}{\sigma_L + 1}},$$

$$(SS11) \quad i = [\mu - (1 - \delta)] \left\{ \frac{\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) (1 - \alpha) (\mu - b\beta)}{\left[\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) - \mu + (1 - \delta) \right] \psi_L(\mu - b)} \right\}^{\frac{1}{\sigma_L + 1}} \left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right)^{\frac{1}{\alpha-1}},$$

$$(SS12) \quad \tilde{\lambda} = (1 - \alpha) \left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right)^{\frac{\alpha}{1-\alpha}} \psi_L \left\{ \frac{(1 - \alpha) \left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) (\mu - b\beta)}{\left[\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) - \mu + (1 - \delta) \right] \psi_L(\mu - b)} \right\}^{\frac{\sigma_L}{\sigma_L + 1}},$$

$$(SS13) \quad c = \left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right)^{\frac{1}{\alpha-1}} \left[\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) - \mu + (1 - \delta) \right] \left\{ \frac{\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) (1 - \alpha) (\mu - b\beta)}{\left[\left(\frac{\frac{\mu}{\beta} - 1 + \delta}{\alpha} \right) - \mu + (1 - \delta) \right] \psi_L(\mu - b)} \right\}^{\frac{1}{\sigma_L + 1}}.$$

D Linearized Equations

The linearized system of equations is as follows, where:

$$\hat{x}_t = \frac{dx_t}{x},$$

$$(11) \quad h^{1-\alpha} \left(\frac{k}{\mu}\right)^\alpha \left[(1-\alpha) z_t + (1-\alpha) \hat{h}_t + \alpha \hat{k}_t - \alpha u_t \right] - \hat{c}_t - \hat{i}_t = 0,$$

$$(12) \quad -\hat{k}_{t+1} + \frac{(1-\delta)}{\mu} (\hat{k}_t - u_t) + \frac{i}{k} \hat{i}_t = 0,$$

$$(13) \quad \left(c - \frac{bc}{\mu}\right)^{-2} \left[-\hat{c}_t + \frac{bc}{\mu} \hat{c}_{t-1} - \frac{bc}{\mu} u_t \right] - \tilde{\lambda} \hat{\lambda}_t \\ + b\beta (\mu - b)^{-2} c^{-1} (\mu \mathbf{E}_t \hat{c}_{t+1} - b \hat{c}_t + \mu \mathbf{E}_t u_{t+1}) = 0,$$

$$(14) \quad -\hat{w}_t + \hat{\phi}_t + (1-\alpha) z_t - \alpha \hat{h}_t + \alpha \hat{k}_t - \alpha u_t = 0,$$

$$(15) \quad -\hat{\pi}_t - \hat{\pi}_t^W + \beta \mathbf{E}_t \hat{\pi}_{t+1} + \beta \mathbf{E}_t \hat{\pi}_{t+1}^W + \frac{\theta_h - 1}{\zeta_w} \hat{\varphi}_t = 0,$$

$$(16) \quad -\hat{\varphi}_t + \sigma_L \hat{h}_t - \hat{\lambda}_t - \hat{w}_t = 0,$$

$$(17) \quad -\hat{r}_t^K + \hat{\phi}_t + (1-\alpha) \hat{z}_t + (1-\alpha) \hat{h}_t + (\alpha - 1) \hat{k}_t + (1-\alpha) u_t = 0,$$

$$(18) \quad -\hat{P}_{K',t} + \mathbf{E}_t \hat{\lambda}_{t+1} - \mathbf{E}_t u_{t+1} - \hat{\lambda}_t + \frac{\beta r^K}{\mu} \mathbf{E}_t \hat{r}_{t+1}^K + \frac{\beta(1-\delta)}{\mu} \mathbf{E}_t \hat{P}_{K',t+1} = 0,$$

$$(19) \quad \hat{P}_{K',t} - (1+\beta) S'' \mu^2 \hat{i}_t + \mu^2 S'' \hat{i}_{t-1} + \beta S'' \mu^2 \mathbf{E}_t \hat{i}_{t+1} = 0,$$

$$(110) \quad -\hat{\pi}_t + \beta \mathbf{E}_t \hat{\pi}_{t+1} + \frac{\theta_p}{\zeta_p} \hat{\phi}_t = 0,$$

$$(111) \quad -R^n \hat{R}_t^n + \rho R^n \hat{R}_{t-1}^n + (1-\rho) \eta \mathbf{E}_t \hat{\pi}_{t+1} + (1-\rho) (1-\alpha) \eta_y z_t \\ + (1-\rho) (1-\alpha) \eta_y \hat{h}_t + (1-\rho) \alpha \eta_y \hat{k}_t = 0,$$

$$(112) \quad \mathbf{E}_t \hat{\pi}_{t+1} - \hat{R}_t^n - \mathbf{E}_t \hat{\lambda}_{t+1} + \hat{\lambda}_t + \mathbf{E}_t \hat{u}_{t+1} = 0,$$

$$(113) \quad -\hat{\pi}_t^W + \hat{w}_t - \hat{w}_{t-1} = 0.$$

E Parameters

Calibrated parameters are shown in Table 9. Because the model is solved at quarterly intervals, the parameters are in quarterly terms.

The parameters are calibrated to the same values used by CIMR, except for ζ_p , ζ_w , μ and S'' . Because we use the Rotemberg-type adjustment while Calvo (1983)-type staggered price setting is assumed by CIMR, we set ζ_p and ζ_w so that the coefficients on the output gap and the real wage gap are equal in these two settings.⁷⁸ For example, according to Calvo pricing, the linearized new Keynesian Phillips curve, which is the counterpart to (110), is

$$-\widehat{\pi}_t + \beta E_t \widehat{\pi}_{t+1} + \frac{(1 - \xi_p)(1 - \beta \xi_p)}{\xi_p} \widehat{\phi}_t = 0.$$

Because ξ_p is assumed to be 0.63 by CIMR, we set ζ_p to 27.454. Similarly, we set ζ_w to 199.0819.

Concerning μ , although it is straightforward to incorporate trend growth in the model, we assume an average trend growth rate of zero so that we can examine the effect of anticipated shocks without having to worry about scaling. However, this does not affect the results.

For investment growth adjustment costs, we assume a slightly different functional form from that used by CIMR. Given that the aim of this paper is to determine whether the expectation-driven business cycle can be generated from empirically plausible parameters, we instead use the standard functional form for investment

⁷⁸Roberts (1995) shows that the linearized versions of the new Keynesian Phillips curve based on these two assumptions are equivalent.

Table 9: Parameter values

Parameter	Value	Description and Definitions
θ_p	6	$\theta_p / (\theta_p - 1)$ is the markup in the goods market
θ_w	21	$\theta_w / (\theta_w - 1)$ is the markup in the labor market
ζ_p	27.454	The Rotemberg adjustment cost in goods
ζ_w	199.0819	The Rotemberg adjustment cost in labor
α	0.4	Labor share
b	0.63	Habit formation parameter
β	$1.01358^{-.25}$	Subjective discount factor
μ	1	The average growth rate
ψ_L	109.82	The level of labor dis-utility
S''	2.48	The level of investment adjustment costs
ρ	0.81	Coefficient on the lagged interest rate
η	1.95	Coefficient on the inflation rate
η_y	0.18	Coefficient on the output gap
ρ_u	0.83	AR (1) parameter on the growth shock
ρ_z	0.83	AR (1) parameter on the level shock
p	4	A shock is expected to occur at p

adjustment costs adopted by Christiano et al. (2005) and Smets and Wouters (2003).

Therefore, S'' is set to the estimated value reported in Christiano et al. (2005).

Furthermore, instead of following CIMR in assuming the partial indexation of prices and wages, we obtain results based on both full-indexation and no indexation.

In the full-indexation case, the Rotemberg-type adjustment cost is written as

$$\frac{\zeta_p}{2} \left(\frac{P_{j,t}}{P_{j,t-1}} / \frac{P_{t-1}}{P_{t-2}} - 1 \right)^2 Y_t.$$

A similar functional form is used for wage adjustment costs.

When the real model is simulated, we choose large values for θ_p , θ_w and η and choose values for ζ_p and ζ_w that are close to zero. Furthermore, we alter the monetary policy rule from one based on the one-period ahead inflation rate to one based on the current inflation rate.

References

- Adolfson, Malin, Stefan Laseen, Jesper Linde, and Mattias Villani,** “Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through,” *Journal of International Economics*, July 2007, 72 (2), 481–511.
- Aguiar, Mark and Gita Gopinath,** “Emerging Market Business Cycles: The Cycle Is the Trend,” *Journal of Political Economy*, February 2007, 115 (1), 69–102.
- Aiyagari, S. Rao,** “Optimal Capital Income Taxation with Incomplete Markets, Borrowing Constraints, and Constant Discounting,” *Journal of Political Economy*, December 1995, 103 (6), 1158–75.
- Altig, David, Lawrence J. Christiano, Martin Eichenbaum, and Jesper Linde,** “Firm-Specific Capital, Nominal Rigidities and the Business Cycle,” NBER Working Paper 11034, National Bureau of Economic Research January 2005.
- Andolfatto, David,** “Business Cycles and Labor-Market Search,” *American Economic Review*, March 1996, 86 (1), 112–32.
- Aoki, Kosuke,** “Optimal Monetary Policy Responses to Relative-Price Changes,” *Journal of Monetary Economics*, August 2001, 48 (1), 55–80.
- , “On the Optimal Monetary Policy Response to Noisy Indicators,” *Journal of Monetary Economics*, April 2003, 50 (3), 501–523.

Auerbach, Alan and Lawrence Kotlikoff, *Dynamic Fiscal Policy*, Cambridge: Cambridge University Press, 1987.

Bansal, Ravi and Amir Yaron, “Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles,” *Journal of Finance*, August 2004, 59 (4), 1481–1509.

Barro, Robert J. and Robert G. King, “Time-Separable Preferences and Intertemporal-Substitution Models of Business Cycles,” *The Quarterly Journal of Economics*, November 1984, 99 (4), 817–839.

Basu, Susanto, John G. Fernald, and Miles S. Kimball, “Are Technology Improvements Contractionary?,” *American Economic Review*, December 2006, 96 (5), 1418–1448.

Bean, Charles R., “Global Demographic Change : Some Implications for Central Banks : Overview Panel,” *Proceedings*, 2004, (Aug), 447–454.

Beaudry, Paul and Franck Portier, “An Exploration into Pigou’s Theory of Cycles,” *Journal of Monetary Economics*, September 2004, 51 (6), 1183–1216.

— and — , “Stock Prices, News, and Economic Fluctuations,” *American Economic Review*, September 2006, 96 (4), 1293–1307.

— , **Fabrice Collard, and Franck Portier**, “Gold Rush Fever in Business Cycles,” NBER Working Paper 12710, National Bureau of Economic Research November 2006.

- Benassy, Jean-Pascal**, “Taste for Variety and Optimum Production Patterns in Monopolistic Competition,” *Economics Letters*, July 1996, 52 (1), 41–47.
- Benhabib, Jess, Richard Rogerson, and Randall Wright**, “Homework in Macroeconomics: Household Production and Aggregate Fluctuations,” *Journal of Political Economy*, December 1991, 99 (6), 1166–87.
- Benigno, Pierpaolo and Michael Woodford**, “Inflation Stabilization and Welfare: The Case of a Distorted Steady State,” *Journal of the European Economic Association*, December 2005, 3 (6), 1185–1236.
- Bergin, Paul R. and Giancarlo Corsetti**, “Towards a Theory of Firm Entry and Stabilization Policy,” NBER Working Paper 11821, National Bureau of Economic Research December 2005.
- Bernanke, Ben S., Mark Gertler, and Simon Gilchrist**, “The Financial Accelerator in a Quantitative Business Cycle Framework,” in John. B. Taylor and Michael Woodford, eds., *Handbook of Macroeconomics*, Vol. 1 of *Handbook of Macroeconomics*, Elsevier, June 1999, chapter 21, pp. 1341–1393.
- Bewley, Truman**, “The Permanent Income Hypothesis: A Theoretical Formulation,” *Journal of Economic Theory*, December 1977, 16 (2), 252–292.
- Bilbiie, Florin, Fabio Ghironi, and Marc J. Melitz**, “Business Cycles and Firm Dynamics,” Technical Report 2005.

— , — , and — , “Monopoly Power and Endogenous Variety in Dynamic Stochastic General Equilibrium : Distortions and Remedies,” June 2006. Mimeo, Nuffield College.

— , — , and — , “Monetary Policy and Business Cycles with Endogenous Entry and Product Variety,” *forthcoming in NBER Macroeconomics Annual 2007*, 2007.

Bils, Mark and Peter J. Klenow, “Some Evidence on the Importance of Sticky Prices,” *Journal of Political Economy*, October 2004, *112* (5), 947–985.

Blanchard, Olivier and Jordi Galí, “Real Wage Rigidities and the New Keynesian Model,” *Journal of Money, Credit and Banking*, 02 2007, *39* (s1), 35–65.

Blanchard, Olivier J., “Debt, Deficits, and Finite Horizons,” *Journal of Political Economy*, April 1985, *93* (2), 223–47.

— and **Charles M. Kahn**, “The Solution of Linear Difference Models under Rational Expectations,” *Econometrica*, July 1980, *48* (5), 1305–1311.

Braun, Richard A., “Tax Disturbances and Real Economic Activity in the Postwar United States,” *Journal of Monetary Economics*, June 1994, *33* (3), 441–462.

Broda, Christian, “Consumer Price Index Biases and Their Impact on Policy,” *International Perspectives*, July 2004, *32*.

— and **David E. Weinstein**, “Globalization and the Gains from Variety,” *The Quarterly Journal of Economics*, May 2006, *121* (2), 541–585.

- Burnside, Craig and Martin Eichenbaum**, “Factor-Hoarding and the Propagation of Business-Cycle Shocks,” *American Economic Review*, December 1996, 86 (5), 1154–74.
- Calvo, Guillermo A.**, “Staggered Prices in A Utility-Maximizing Framework,” *Journal of Monetary Economics*, September 1983, 12 (3), 383–398.
- Carceles-Poveda, Eva and Daniele Coen-Pirani**, “Shareholders Unanimity with Incomplete Markets,” Mimeo, David A. Tepper School of Business, Carnegie Mellon University January 2008.
- Carlstrom, Charles T. and Timothy S. Fuerst**, “Investment and interest rate policy: a discrete time analysis,” *Journal of Economic Theory*, July 2005, 123 (1), 4–20.
- Cass, David**, “Optimum Growth in an Aggregate Model of Capital Accumulation,” *Review of Economic Studies*, July 1965, 32 (3), 233–240.
- Champ, Bruce and Scott Freeman**, *Modeling Monetary Economies*, 2 ed., Cambridge: Cambridge University Press, 2001.
- Choudhary, M. Ali and Paul Levine**, “Idle Worship,” *Economics Letters*, January 2006, 90 (1), 77–83.
- Christiano, Lawrence J.**, “Solving Dynamic Equilibrium Models by a Method of Undetermined Coefficients,” *Computational Economics*, October 2002, 20 (1-2), 21–55.

- , **Cosmin Ilut, Roberto Motto, and Massimo Rostagno**, “Monetary Policy and Stock Market Boom-Bust Cycles,” March 2007. Mimeo, Northwestern University.
- , **Martin Eichenbaum, and Charles L. Evans**, “Monetary Policy Shocks: What Have We Learned and to What End?,” in John B. Taylor and Michael Woodford, eds., *Handbook of Macroeconomics*, Vol. 1 of *Handbook of Macroeconomics*, Elsevier, January 1999, chapter 21, pp. 65–148.
- , — , and — , “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy,” *Journal of Political Economy*, February 2005, *113* (1), 1–45.
- , **Roberto Motto, and Massimo Rostagno**, “Shocks, Structures or Monetary Policies? The Euro Area and US after 2001,” NBER Working Paper 13521, National Bureau of Economic Research October 2007.
- Clarida, Richard, Jordi Galí, and Mark Gertler**, “The Science of Monetary Policy: A New Keynesian Perspective,” *Journal of Economic Literature*, December 1999, *37* (4), 1661–1707.
- Coase, Ronald H.**, “The Problem of Social Cost,” *The Journal of Law and Economics*, October 1960, *3* (1), 1–44.
- Cole, Harold L. and Lee K. Ohanian**, “The U.S. and U.K. Great Depressions through the Lens of Neoclassical Growth Theory,” *American Economic Review*, May 2002, *92* (2), 28–32.

- Cooley, Thomas**, *Frontiers of Business Cycle Research*, Princeton: Princeton University Press, 1995.
- Corsetti, Giancarlo, Philippe Martin, and Paolo Pesenti**, “Productivity, Terms of Trade and the ‘Home Market Effect’,” *Journal of International Economics*, September 2007, *73* (1), 99–127.
- Denhaan, Wouter and Georg Kaltenbrunner**, “Anticipated Growth and Business Cycles in Matching Models,” January 2007. Mimeo, London Business School.
- Dixit, Avinash K. and Joseph E. Stiglitz**, “Monopolistic Competition and Optimum Product Diversity,” *American Economic Review*, June 1977, *67* (3), 297–308.
- Doepke, Matthias and Martin Schneider**, “Inflation and the Redistribution of Nominal Wealth,” *Journal of Political Economy*, December 2006, *114* (6), 1069–1097.
- Dupor, Bill**, “Investment and Interest Rate Policy,” *Journal of Economic Theory*, May 2001, *98* (1), 85–113.
- Edge, Rochelle M.**, “A Utility-Based Welfare Criterion in a Model with Endogenous Capital Accumulation,” Technical Report 2003.
- , **Thomas Laubach, and John C. Williams**, “Learning and Shifts in Long-Run Productivity Growth,” *Journal of Monetary Economics*, November 2007, *54* (8), 2421–2438.

- Epstein, Larry G. and Stanley E. Zin**, “Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: An Empirical Analysis,” *Journal of Political Economy*, April 1991, *99* (2), 263–86.
- Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin**, “Optimal Monetary Policy with Staggered Wage and Price Contracts,” *Journal of Monetary Economics*, October 2000, *46* (2), 281–313.
- , **Luca Guerrieri, and Christopher Gust**, “SIGMA: A New Open Economy Model for Policy Analysis,” *International Journal of Central Banking*, March 2006, *2* (1).
- Evans, George W. and Seppo Honkapohja**, *Learning and Expectations in Macroeconomics*, Princeton: Princeton University Press, 2001.
- Faia, Ester**, “Optimal Monetary Policy Rules with Labor Market Frictions,” Working Paper Series 698, European Central Bank November 2006.
- and **Tommaso Monacelli**, “Optimal Interest Rate Rules, Asset Prices, and Credit Frictions,” *Journal of Economic Dynamics and Control*, October 2007, *31* (10), 3228–3254.
- Feenstra, Robert C.**, “A Homothetic Utility Function for Monopolistic Competition Models, without Constant Price Elasticity,” *Economics Letters*, January 2003, *78* (1), 79–86.
- Friedman, Milton**, *The Optimum Quantity of Money and Other Essays*, Chicago: Aldine Publishing Company, 1969.

Fujiwara, Ippei and Heedon Kang, “Expectation Shock Simulation with DYNARE,” QM&RBC Codes, Quantitative Macroeconomics & Real Business Cycles August 2006. available at <http://ideas.repec.org/c/dge/qmrbcd/163.html>.

—, **Kazuo Fukuda, Ichiro Muto, Yosuke Shigemi, and Wataru Takahashi**, “Frontiers in Monetary Theory and Policy: Summary of the 2008 International Conference Organized by the Institute for Monetary and Economic Studies of the Bank of Japan,” IMES Discussion Paper Series 08-E-20, Institute for Monetary and Economic Studies, Bank of Japan August 2008.

—, **Yasuo Hirose, and Mototsugu Shintani**, “Can News Be a Major Source of Aggregate Fluctuations? A Bayesian DSGE Approach,” IMES Discussion Paper Series 08-E-16, Institute for Monetary and Economic Studies, Bank of Japan July 2008.

Galí, Jordi, “Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?,” *American Economic Review*, March 1999, 89 (1), 249–271.

— and **Pau Rabanal**, “Technology Shocks and Aggregate Fluctuations: How Well Does the RBS Model Fit Postwar U.S. Data?,” NBER Working Paper 10636, National Bureau of Economic Research July 2004.

Gertler, Mark, “Government Debt and Social Security in a Life-Cycle Economy,” *Carnegie-Rochester Conference Series on Public Policy*, June 1999, 50, 61–110.

Ghironi, Fabio, “The Role of Net Foreign Assets in a New Keynesian Small Open Economy Model,” Technical Report 2006.

— and **Marc J. Melitz**, “International Trade and Macroeconomic Dynamics with Heterogeneous Firms,” *The Quarterly Journal of Economics*, August 2005, *120* (3), 865–915.

Giannoni, Marc P. and Michael Woodford, “Optimal Interest-Rate Rules: I. General Theory,” NBER Working Papers 9419, National Bureau of Economic Research, Inc January 2003.

— and —, “Optimal Inflation Targeting Rules,” NBER Working Papers 9939, National Bureau of Economic Research, Inc September 2003.

— and —, “Optimal Interest-Rate Rules: II. Applications,” NBER Working Papers 9420, National Bureau of Economic Research, Inc January 2003.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W. Huffman, “Investment, Capacity Utilization, and the Real Business Cycle,” *American Economic Review*, June 1988, *78* (3), 402–17.

Hansen, Gary D., “Indivisible Labor and the Business Cycle,” *Journal of Monetary Economics*, November 1985, *16* (3), 309–327.

Heathcote, Jonathan and Fabrizio Perri, “Financial Globalization and Real Regionalization,” *Journal of Economic Theory*, November 2004, *119* (1), 207–243.

- Jaimovich, Nir and Sergio Rebelo**, “Can News about the Future Drive the Business Cycle?,” NBER Working Paper 12537, National Bureau of Economic Research September 2006.
- Khan, Aubhik, Robert G. King, and Alexander L. Wolman**, “Optimal Monetary Policy,” *Review of Economic Studies*, October 2003, 70 (4), 825–860.
- Kilponen, Juha and Antti Ripatti**, “Labour and Product Market Competition in a Small Open Economy, Simulation results using a DGE model of the Finnish economy,” Research Discussion Papers 5/2006, Bank of Finland April 2006.
- , — , and **Jouko Vilmunen**, “Aino: The Bank of Finland’s New Dynamic General Equilibrium Model of the Finnish Economy,” 2004.
- , **Helvi Kinnunen, and Antti Ripatti**, “Demographic Uncertainty and Labour Market Imperfections in Small Open Economy,” *Computing in Economics and Finance* 2006 227, Society for Computational Economics July 2006.
- Kim, Jinill**, “What Determines Aggregate Returns to Scale?,” *Journal of Economic Dynamics and Control*, June 2004, 28 (8), 1577–1594.
- and **Sunghyun Henry Kim**, “Two Pitfalls of Linearization Methods,” *Journal of Money, Credit and Banking*, 06 2007, 39 (4), 995–1001.
- , **Sunghyun Kim, Ernst Schaumburg, and Christopher A. Sims**, “Calculating and Using Second Order Accurate Solutions of Discrete Time Dynamic Equilibrium Models,” Technical Report 2003.

- Kimball, Miles S.**, “The Quantitative Analytics of the Basic Neomonetarist Model,” *Journal of Money, Credit and Banking*, November 1995, 27 (4), 1241–1277.
- King, Robert G., Charles I. Plosser, and Sergio T. Rebelo**, “Production, growth and business cycles : I. The basic neoclassical model,” *Journal of Monetary Economics*, 1988, 21 (2-3), 195–232.
- , — , and — , “Production, growth and business cycles : II. New directions,” *Journal of Monetary Economics*, 1988, 21 (2-3), 309–341.
- Klenow, Peter J. and Oleksiy Kryvtsov**, “State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation,” *The Quarterly Journal of Economics*, August 2008, 123 (3), 863–904.
- Kobayashi, Keiichiro, Tomoyuki Nakajima, and Masaru Inaba**, “Collateral Constraint and News-Driven Cycles,” Discussion Paper 07013, Research Institute of Economy, Trade and Industry (RIETI) March 2007.
- Kocherlakota, Narayana**, “Model Fit and Model Selection,” *Review*, 2007, (Jul), 349–360.
- Koopmans, Tjalling**, “On the Concept of Optimal Economic Growth,” in “The Economic Approach to Development Planning,” North-Holland, 1965.
- Kydland, Finn E. and Edward C. Prescott**, “Time to Build and Aggregate Fluctuations,” *Econometrica*, November 1982, 50 (6), 1345–70.

- Laxton, Douglas and Paolo Pesenti**, “Monetary Rules for Small, Open, Emerging Economies,” *Journal of Monetary Economics*, July 2003, 50 (5), 1109–1146.
- Lerner, Abba P.**, “The Concept of Monopoly and the Measurement of Monopoly Power,” *Review of Economic Studies*, June 1934, 1 (2), 157–175.
- Levin, Andrew T., Alexei Onatski, John C. Williams, and Noah Williams**, “Monetary Policy Under Uncertainty in Micro-Founded Macroeconometric Models,” *NBER Macroeconomics Annual 2005*, 2005, pp. 229–287.
- and **J. David Lopez-Salido**, “Monetary Policy Implications of Endogenous Capital Accumulation,” *Computing in Economics and Finance* 2003 122, Society for Computational Economics August 2003.
- and **Tack Yun**, “Reconsidering the Natural Rate Hypothesis in a New Keynesian Framework,” *Journal of Monetary Economics*, July 2007, 54 (5), 1344–1365.
- , **J. David Lopez-Salido, and Tack Yun**, “Strategic Complementarities and Optimal Monetary Policy,” CEPR Discussion Papers 6423, C.E.P.R. Discussion Papers August 2007.
- Ljungqvist, Lars and Harald Uhlig**, “Tax Policy and Aggregate Demand Management under Catching Up with the Joneses,” *American Economic Review*, June 2000, 90 (3), 356–366.
- Lucas, Robert Jr. and Nancy L. Stokey**, “Optimal Growth with Many Consumers,” *Journal of Economic Theory*, February 1984, 32 (1), 139–171.

- Lucca, David O.**, “Resuscitating Time-to-Build,” January 2007. Mimeo, Board of Governors of the Federal Reserve System.
- Mash, Richard**, “Endogenous Indexing and Monetary Policy Models,” Kiel Working Papers 1358, Kiel Institute for the World Economy June 2007.
- McGrattan, Ellen R.**, “The Macroeconomic Effects of Distortionary Taxation,” *Journal of Monetary Economics*, June 1994, *33* (3), 573–601.
- Melitz, Marc J.**, “The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity,” *Econometrica*, November 2003, *71* (6), 1695–1725.
- Merz, Monika**, “Search in the Labor Market and the Real Business Cycle,” *Journal of Monetary Economics*, 1995, *36*.
- Miles, David**, “Should Monetary Policy Be Different in a Greyer World?,” in Alan Auerbach and Heinz Hermann, eds., *Aging, Financial Markets and Monetary Policy*, Springer, 2002.
- Mortensen, Dale T. and Christopher A. Pissarides**, “Job Creation and Job Destruction in the Theory of Unemployment,” *Review of Economic Studies*, July 1994, *61* (3), 397–415.
- Nakamura, Emi and Jon Steinsson**, “Five Facts about Prices: A Reevaluation of Menu Cost Models,” *Quarterly Journal of Economics* (forthcoming), Department of Economics, Columbia University May 2008.

- Nessen, Marianne and David Vestin**, “Average Inflation Targeting,” *Journal of Money, Credit and Banking*, October 2005, *37* (5), 837–63.
- Obstfeld, Maurice and Kenneth Rogoff**, “Exchange Rate Dynamics Redux,” *Journal of Political Economy*, June 1995, *103* (3), 624–60.
- Orphanides, Athanasios and John C. Williams**, “Robust Monetary Policy Rules with Unknown Natural Rates,” *Brookings Paper on Economic Activity*, 2002, *2002* (2), 63–118.
- Pigou, Arthur C.**, *Industrial Fluctuations*, London: MacMillan and Co., 1926.
- Ramsey, Frank**, “A Mathematical Theory of Saving,” *Economic Journal*, December 1928, *38*, 543–559.
- Reis, Ricardo**, “Inattentive Consumers,” *Journal of Monetary Economics*, November 2006, *53* (8), 1761–1800.
- Roberts, John M.**, “New Keynesian Economics and the Phillips Curve,” *Journal of Money, Credit and Banking*, November 1995, *27* (4), 975–84.
- Rogerson, Richard**, “Indivisible Labor, Lotteries and Equilibrium,” *Journal of Monetary Economics*, January 1988, *21* (1), 3–16.
- Rogoff, Kenneth S.**, “Impact of Globalization on Monetary Policy,” *Proceedings*, 2006, pp. 265–305.
- Rotemberg, Julio J.**, “Sticky Prices in the United States,” *Journal of Political Economy*, December 1982, *90* (6), 1187–1211.

- and **Michael Woodford**, “An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy,” *NBER Macroeconomics Annual*, 1997, 12, 297–346.
- Samuelson, Paul A.**, “An Exact Consumption-Loan Model of Interest with or without the Social Contrivance of Money,” *Journal of Political Economy*, December 1958, 66 (6), 467–482.
- Schmitt-Grohé, Stephanie and Martín Uribe**, “Solving Dynamic General Equilibrium Models Using a Second-order Approximation to the Policy Function,” *Journal of Economic Dynamics and Control*, January 2004, 28 (4), 755–775.
- and —, “Optimal Inflation Stabilization in a Medium-Scale Macroeconomic Model,” 2006. Mimeo, Duke University.
- Schorfheide, Frank**, “Loss Function-Based Evaluation of DSGE Models,” *Journal of Applied Econometrics*, 2000, 15 (6), 645–670.
- Shimer, Robert**, “The Cyclical Behavior of Equilibrium Unemployment and Vacancies,” *American Economic Review*, March 2005, 95 (1), 25–49.
- Sims, Christopher A.**, “Macroeconomics and Reality,” *Econometrica*, January 1980, 48 (1), 1–48.
- , “Implications of Rational Inattention,” *Journal of Monetary Economics*, April 2003, 50 (3), 665–690.

Smets, Frank and Raf Wouters, “An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area,” *Journal of the European Economic Association*, September 2003, 1 (5), 1123–1175.

— and **Rafael Wouters**, “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach,” *American Economic Review*, June 2007, 97 (3), 586–606.

Sveen, Tommy and Lutz Weinke, “New Perspectives on Capital, Sticky Prices, and the Taylor Principle,” *Journal of Economic Theory*, July 2005, 123 (1), 21–39.

Svensson, Lars E. O., “What Is Wrong with Taylor Rules? Using Judgment in Monetary Policy through Targeting Rules,” *Journal of Economic Literature*, June 2003, 41 (2), 426–477.

Taylor, John B., “Staggered Wage Setting in a Macro Model,” *American Economic Review*, May 1979, 69 (2), 108–13.

—, “Aggregate Dynamics and Staggered Contracts,” *Journal of Political Economy*, February 1980, 88 (1), 1–23.

—, “Discretion versus Policy Rules in Practice,” *Carnegie-Rochester Conference Series on Public Policy*, December 1993, 39, 195–214.

Townsend, Robert M., “Optimal Contracts and Competitive Markets with Costly State Verification,” *Journal of Economic Theory*, October 1979, 21 (2), 265–293.

- Vigfusson, Robert J.**, “The Delayed Response to a Technology Shock: A Flexible Price Explanation,” Technical Report 2004.
- Walsh, Carl E.**, *Monetary Theory and Policy*, 2 ed., Cambridge: The MIT Press, 2003.
- Williamson, Stephen D.**, “Monetary Policy and Distribution,” Technical Report 2005.
- Woodford, Michael**, *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton: Princeton University Press, 2003.
- Yaari, Menahem**, “Uncertain Lifetime, Life Insurance, and the Theory of the Consumer,” *Review of Economic Studies*, April 1965, 32 (2), 137–150.
- Yun, Tack**, “Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles,” *Journal of Monetary Economics*, April 1996, 37 (2-3), 345–370.