

Agency Costs and the Monetary Transmission Mechanism

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Abstract

Once New Keynesian (NK) theory (see, e.g., Woodford 2003) is combined with a standard model of investment (see, e.g., Thomas 2002), the resulting framework loses its ability to generate a realistic monetary transmission mechanism. This is the puzzle uncovered in Reiter et al. (2013). The simple economic reason behind it is the unrealistically large interest rate elasticity of investment, as implied by standard investment theory. In order to address this puzzle we develop a NK model featuring fully flexible investment combined with a financial friction in the spirit of Carlstrom and Fuerst (1997). This model is used to isolate the quantitative importance of the financial friction for the monetary transmission mechanism.

Keywords: Financial Frictions, Sticky Prices.

JEL Classification: E22, E31, E32

1 Introduction

What explains the short-run effects of monetary policy on real variables of interest? Over the past twenty years dynamic stochastic general equilibrium (DSGE) models featuring nominal rigidities, such as sticky prices or wages combined with monopolistic competition, have emerged as the standard tool to analyze questions related to the dynamic consequences of monetary policy changes. Those models are generally called New Keynesian (NK) theory. Its micro-founded structure makes this theory in principle usable for policy analysis and, in fact, NK theory is being used in the academic world as well as in central banks and other policy institutions to understand a wide range of issues related to monetary policy. However, the normative results of NK theory are only useful if its positive predictions are relevant from an empirical point of view. The monetary transmission mechanism is therefore generally viewed as being the hallmark of NK theory (see, e.g., Woodford 2003, p. 6, and Galí 2015, p. 1).

It is well understood that smoothness in aggregate capital accumulation gives rise to a reasonable monetary transmission mechanism in the context of NK models.¹ This has motivated Christiano et al. (2005) and Woodford (2005) to introduce adjustment costs into the investment block of the NK framework, and most of the related literature has followed their lead.² But the existence of those adjustment costs makes NK models inconsistent with the observed lumpiness in plant-level investment.³ Motivated by this problem our work in Reiter et al. (2013) uses standard

¹An alternative way of engineering an empirically relevant monetary transmission mechanism is to simply assume capital accumulation away. That modeling choice is also widespread in the literature (see, e.g., Galí 2015 among many others).

²Specifically, Christiano et al. (2005) assume a convex investment adjustment cost, whereas Woodford (2005) postulates a convex capital adjustment cost.

³That lumpiness is reported by, e.g., Doms and Dunne (1998), Thomas (2002) and Khan and Thomas (2008). In the context of our theory there is no distinction between a plant and a firm and we therefore use those terms interchangeably.

investment theory (see, e.g., Thomas 2002) to make an otherwise conventional NK DSGE model consistent with the lumpy nature of capital adjustment at the micro level. In the context of the resulting framework the following puzzle emerges. Monetary shocks are shown to have dynamic consequences whose strength and persistence are out of line with the available empirical evidence on the way in which comparable shocks are propagated in the data. Specifically, the impact responses of investment and output to a change in the nominal interest rate become very large and the dynamic consequences of that shock are only short-lived.⁴ In a nutshell, the reason behind our main result in Reiter et al. (2013) is that non-convex adjustment costs which are routinely assumed in the investment literature do not rationalize a realistic interest rate sensitivity of investment. The (S,s) nature of investment decisions is crucial to understand this result. In response to an expansionary monetary policy shock firms choose to undertake some of the investment activity that they would have otherwise done later. This mechanism, which is often called an extensive margin effect (see, e.g., Caballero and Engel 2007), is the most important driving force behind our main result in Reiter et al. (2013).

The motivation for the present paper originates in this puzzle. In fact, we assess the quantitative importance of a simple economic mechanism to address it. More concretely, Carlstrom and Fuerst (1997) show that a financial friction in the process of capital production might act as a smoothing device. In order to isolate the role of this mechanism we formulate a NK model featuring otherwise fully flexible investment combined with a financial friction in their spirit.⁵ That financial friction

⁴Given the large size of the literature on the monetary transmission mechanism of might wonder why the puzzle presented in Reiter et al. (2013) has not been uncovered before. The simple reason is that the general equilibrium consequences of multiple (S,s) decisions at the micro level can not easily be computed. In Reiter et al. (2013) we have relied on the method developed in Reiter (2009, 2010) to bring this about.

⁵Carlstrom and Fuerst (2001) also propose a monetary version of their (1997) RBC model. But this involves a cash-in-advance constraint, whereas we consider a standard cashless NK economy.

can in principle perfectly coexist with lumpiness in plant-level investment. This is important because many other frictions make the model inconsistent with lumpy investment, once those frictions have a size that gives rise to a realistic monetary transmission mechanism.⁶ Our assumption of flexible investment is clearly extreme in the sense that this makes it even more difficult (than it is under a (S,s) modelling of investment decisions) to obtain a realistic monetary transmission mechanism.⁷ It is therefore interesting that a plausible calibration of the financial friction under consideration makes our model go a long way towards an empirically relevant monetary transmission mechanism.

The remainder of the paper is organized as follows. Section 2 outlines the model. Section 3 presents the dynamic analysis and section 4 concludes.

2 The Model

Our model integrates a financial friction in the spirit of Carlstrom and Fuerst (1997) into an otherwise standard New Keynesian model of the monetary transmission mechanism. Fig. 1 summarizes the model structure.

[Figure 1 about here.]

Since the details of the model features have been discussed elsewhere (see, Carlstrom and Fuerst 1997 for a discussion of the financial friction and, e.g., Woodford 2003 or Galí 2015 for textbook treatments of the New Keynesian elements) we turn

⁶For instance, Reiter et al. (2013) show that a convex capital adjustment cost at the firm level combined with a (S,s) restriction on investment gives rise to a realistic monetary transmission mechanism only to the extent that the size of the convex cost is large enough to eliminate a plausible degree of lumpiness in investment.

⁷In the context of their RBC models Thomas (2002) and Khan and Thomas (2008) establish equivalence between (S,s) and flexible investment for aggregate dynamics. This is not true in a NK model. In the context of the latter theory, (S,s) investment turns out to make aggregate capital flexible enough to imply an unrealistic monetary transmission mechanism (see, Reiter et al. 2013), but capital is still smoother than it would be the case under fully flexible investment. We will come back to this later in the text.

directly to the implied set of equilibrium conditions. There is a continuum of firms and each of them is the monopolistically competitive producer of a differentiated good. Firms set prices in a staggered fashion à la Calvo (1983). Each firm has access to the following production function

$$Y_t = F(K_t, (1 - \eta) L_t, \eta), \quad (1)$$

where Y_t is output of its differentiated consumption good. Firms hire labor and rent capital from households and entrepreneurs. Our notation reflects the assumptions that there is a measure $(1 - \eta)$ of households and a measure η of entrepreneurs. Moreover households' labor supply, L_t , is elastic, whereas each entrepreneur supplies inelastically one unit of labor. The capital stock used in time t production is denoted by K_t . Cost minimization on the part of firms implies the following set of factor prices

$$r_t = \frac{F_K(K_t, (1 - \eta) L_t, \eta)}{M_t}, \quad (2)$$

$$w_t = \frac{F_H(K_t, (1 - \eta) L_t, \eta)}{M_t}, \quad (3)$$

$$x_t = \frac{F_{H_e}(K_t, (1 - \eta) L_t, \eta)}{M_t}, \quad (4)$$

where r_t , w_t and x_t denote, respectively, the real rental rate for capital, the real wage and the real wage for entrepreneurial labor. They are given by the associated marginal products combined with the average price markup, M_t .

Households' labor supply equation reads

$$\nu = w_t U'(C_t), \quad (5)$$

where ν is a parameter, reflecting our assumption of a linear disutility associated with

supplying labor. As usual, $U'(C_t)$ indicates the marginal utility of consumption and C_t is the households' time t consumption level of a Dixit-Stiglitz aggregate. Households decide how much of their labor and capital income to consume in the same period, and how much to save by investing in capital accumulation. If a household wishes to purchase capital, it must fund entrepreneurial projects, and these projects are subject to agency problems. As in Carlstrom and Fuerst (1997), households arrange their lending through a capital mutual fund (CMF). For each unit of investment that a household wishes to purchase, it gives q_t consumption goods to the CMF. The additional capital resulting from time t investment becomes productive with a one-period delay and the Euler equation characterizing the optimal consumption/savings decision therefore takes the following standard form

$$q_t U'(C_t) = \beta E_t \left\{ U'(C_{t+1}) [q_{t+1} (1 - \delta) + r_{t+1}] \right\}, \quad (6)$$

where parameter β is the discount factor for utility and parameter δ is the rate of depreciation. The CMF uses the resources obtained from households to provide loans to an infinite number of risk-neutral entrepreneurs utilizing the optimal financial contract analyzed in Carlstrom and Fuerst (1997).

Entrepreneurs get access to the aggregate consumption good through the CMF in exchange for the promise to repay with interest in terms of the capital good they produce. More concretely, an entrepreneur with net worth n who borrows $(i - n)$ consumption goods agrees to repay $(1 - r^k)(i - n)$ capital goods to the lender. Entrepreneurs place their entire net worth as well as the borrowed consumption goods into their capital-creation technology. The latter is assumed to be stochastic. It contemporaneously transforms i consumption goods into ωi units of capital. The random variable ω is i.i.d. across time and entrepreneurs. Agency issues emerge by

assuming that ω is privately observed by the entrepreneur. Others can observe ω only at a monitoring cost of μi units of capital. This information asymmetry creates a moral hazard problem because, without monitoring, the entrepreneur might not wish to tell the true value of ω . The optimal contract, however, incentivizes entrepreneurs to always truthfully report the ω realization. Entrepreneurs also work for firms and generate an associated labor income which prevents them from having a zero level of net worth. A related point is that entrepreneurs do not accumulate net worth to the point that the agency problem disappears. In Carlstrom and Fuerst (1997) that is made sure by assuming that entrepreneurs discount the future more heavily than do households. In our context, this assumption would also guarantee that the above mentioned contracting problem between entrepreneurs and the CMF is well-defined at each point in time. The implied monetary transmission mechanism would, however, become counterfactual. The problematic aspect of this assumption is the large extent to which risk-neutral entrepreneurs engage in intertemporal consumption substitution implying highly volatile equilibrium investment dynamics. We will come back to this later. In order to make our model compatible with an empirically relevant monetary transmission mechanism we adopt instead a classical assumption that has been popularized by Bernanke et al. (1999). Specifically, entrepreneurs are assumed to consume a constant fraction out of their net worth n_t . Entrepreneurial consumption, $C_{e,t}$, therefore takes the following simple form

$$C_{e,t} = \bar{c}_e n_t, \tag{7}$$

with \bar{c}_e denoting the fraction of net worth that entrepreneurs consume in the current period. To raise internal funds entrepreneurs supply labor and rent out capital to firms. They sell the remaining undepreciated capital to the CMF for consumption

goods (the input used in their production technology). In the aggregate, entrepreneurs' budget constraint takes the following form

$$n_t = x_t + \frac{Z_t [q_t (1 - \delta) + r_t]}{\eta}, \quad (8)$$

where Z_t denotes the aggregate entrepreneurial capital stock. The latter evolves according to a law of motion of the form

$$Z_t = \eta n_{t-1} \frac{roi_{t-1}}{q_{t-1}} - \frac{\eta C_{e,t-1}}{q_{t-1}}, \quad (9)$$

with roi_t measuring an entrepreneur's return on investment. The latter takes into account that net worth is leveraged into an investment project. Entrepreneurs keep a fraction of the resulting capital, and capital is priced at q_t . Carlstrom and Fuerst (1997) show that roi_t is determined by

$$roi_t = \frac{q_t f(\bar{\omega}_t, \sigma)}{1 - q_t g(\bar{\omega}_t, \sigma)}, \quad (10)$$

with function $f(\bar{\omega}_t, \sigma)$ measuring the fraction of the expected net capital output received by an entrepreneur. Its first argument is the critical value for idiosyncratic productivity, $\bar{\omega}_t$, which has the property that a project gets monitored if an entrepreneur reports an idiosyncratic productivity level below that value. Its second argument is the standard deviation of the distribution of entrepreneurs' idiosyncratic technology. Similarly, function $g(\bar{\omega}_t, \sigma)$ measures the fraction of the expected net capital output received by the CMF. The aggregate law of motion of the capital stock is of the form

$$K_{t+1} = (1 - \delta) K_t + \eta I_t [1 - \Phi^{norm}(\bar{\omega}_t, \mu_d, \sigma) \mu], \quad (11)$$

where the second term reflects the assumption that capital is produced by entrepreneurs and part of that production is lost due to agency costs. As it turns out, that loss depends on the (linear) monitoring cost μ , the distribution of entrepreneurs' idiosyncratic technology (assumed to be normal with mean μ_d and standard deviation σ) as well as on the critical value for idiosyncratic productivity, $\bar{\omega}_t$. Carlstrom and Fuerst (1997) show how this critical value is obtained from two first-order conditions implied by the agency problem. They read

$$q_t = \frac{1}{1 - \Phi^{norm}(\bar{\omega}_t, \mu_d, \sigma) \mu + \phi^{norm}(\bar{\omega}_t, \mu_d, \sigma) \mu \frac{f(\bar{\omega}_t, \sigma)}{f_\omega(\bar{\omega}_t, \sigma)}}, \quad (12)$$

$$I_t = \frac{n_t}{1 - q_t g(\bar{\omega}_t, \sigma)}. \quad (13)$$

In stating the last two equations we have used the notation $\phi^{norm}(\bar{\omega}_t, \mu_d, \sigma)$ for the density of entrepreneurs' idiosyncratic technology evaluated at the critical value $\bar{\omega}_t$, and $f_\omega(\bar{\omega}_t, \sigma)$ is meant to indicate the derivative of that function with respect to its first argument. The aggregate goods market clearing condition is of the form

$$Y_t = (1 - \eta) C_t + \eta C_{e,t} + \eta I_t. \quad (14)$$

As it is usual in the new Keynesian literature, gross inflation $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ (with P_t denoting the time t price of the aggregate consumption good) is obtained from averaging optimal pricing decisions in a Calvo environment via the price index. The latter implies

$$\Pi_t = [\theta_p + (1 - \theta_p) (p_t^*)^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}, \quad (15)$$

with θ_p denoting the Calvo parameter, i.e., the probability according to which a firm is not allowed to change price in a given period. Parameter ε measures the elasticity of substitution between the differentiated consumption goods in our econ-

omy. Finally, we have used the notation $p_t^* \equiv \frac{P_t^*}{P_{t-1}}$ for the optimal newly set price, P_t^* , that is chosen by all time t price-setters in our model, relative to the price of the consumption good one period earlier. The stochastic discount factor, $Q_{t,t+1}$, for nominal random profits is of the form

$$Q_{t,t+1} \equiv \beta \frac{U'(C_{t+1})}{U'(C_t)} \frac{P_t}{P_{t+1}}. \quad (16)$$

Let us also notice that up to a first-order approximation our model implies a standard inverse relationship between the real marginal cost, κ_t^r , and the average price markup

$$\kappa_t^r = \frac{1}{M_t}. \quad (17)$$

It is convenient for our purposes to characterize the optimal price-setting decision in a standard recursive fashion

$$\Phi_t P_t^* = \mu^p \Psi_t P_t, \quad (18)$$

with $\mu^p \equiv \frac{\varepsilon}{\varepsilon-1}$ denoting the desired frictionless price markup. The variables $\Phi_t \equiv E_t \left\{ \sum_{k=0}^{\infty} \theta_p^k Q_{t,t+k} Y_{t+k} P_{t+k}^\varepsilon P_t^{-\varepsilon} \right\}$ and $\Psi_t \equiv E_t \left\{ \sum_{k=0}^{\infty} \theta_p^k Q_{t,t+k} Y_{t+k} P_{t+k}^\varepsilon \kappa_{t+k}^n P_t^{-\varepsilon-1} \right\}$ with κ_t^n denoting the nominal marginal cost, are determined by the following two forward-looking equations

$$\Phi_t = Y_t + \theta_p E_t \left\{ \Pi_{t+1}^\varepsilon Q_{t,t+1} \Phi_{t+1} \right\}, \quad (19)$$

$$\Psi_t = \kappa_t^r Y_t + \theta_p E_t \left\{ \Pi_{t+1}^{\varepsilon+1} Q_{t,t+1} \Psi_{t+1} \right\}. \quad (20)$$

To close the model we assume a Taylor-type rule for the conduct of monetary policy

$$R_t = (R_{t-1})^{\phi_r} \left[\frac{\Pi}{\beta} \left(\frac{\Pi_t}{\Pi} \right)^{\phi_\pi} \left(\frac{Y_t}{Y} \right)^{\phi_y} \right]^{1-\phi_r} e^{\varepsilon_{r,t}}. \quad (21)$$

The shock, $e_{r,t}$, is *i.i.d.* with zero mean and monetary policy shocks are assumed to be the only source of aggregate uncertainty. Parameters ϕ_π and ϕ_y indicate the long-run responsiveness of the nominal interest rate to changes in current inflation and output,⁸ respectively, and parameter ϕ_r measures interest rate smoothing.

3 The Monetary Transmission Mechanism

We analyze the dynamic consequences of a 100 basis point decrease in the annualized nominal interest rate. The rate of inflation as well as the real interest rate are also annualized. All other variables are measured as the respective log deviation of the original variable from its steady state value. Unless stated otherwise our quantitative results rely on the following baseline calibration.

3.1 Baseline Calibration

The model period is a quarter. The discount factor, β , is set to 0.99, which implies an annualized steady state real interest rate of about 4 percent. Annualized steady state inflation is set to two percent. Some of our baseline parameter values are justified in Reiter et al. (2013). Those include the monetary policy parameter values $\phi_\pi = 1.5$, $\phi_y = 0.5/4$ and $\phi_r = 0.7$. Moreover, the elasticity of substitution between the differentiated goods, ε , is set to 7. We also assume $\theta_p = 0.75$ implying an average expected life-time of a price of 4 quarters. Other parameter values are justified in Carlstrom and Fuerst (1997). In particular, the depreciation rate, δ , is set to 0.02. The production function is assumed to be of the Cobb-Douglas form with capital-share parameter, $\alpha_K = 0.36$, labor-share, $\alpha_H = 0.6399$, and entrepreneurial

⁸Usually, the output gap, i.e., the ratio between equilibrium output and natural output (defined as the equilibrium output under flexible prices) enters the specification of monetary policy. Notice, however, that natural output does not change in response to a monetary disturbance.

labor-share, $\alpha_{He} = 0.001$. The fraction of entrepreneurs, η , is set to 0.003. Our baseline choice for the bankruptcy cost parameter, μ , is 0.25, a value in the plausible range between 0.2 and 0.36. Parameters σ and \bar{c}_e are treated as unobservable. They are chosen to match two empirical values that are also justified in Carlstrom and Fuerst (1997). In particular, we match a quarterly bankruptcy rate of 0.974 as well as an annual risk premium of 187 basis points. In the context of our model, the bankruptcy rate is given by $\Phi^{norm}(\bar{\omega}_t, \mu_d, \sigma)$ and the quarterly risk premium reads $q(1 + r^k) - 1$. Finally, parameter ν is chosen to ensure that households spend one third of their time working.

3.2 Baseline Analysis

Fig. 2 illustrates the dynamic consequences of a 100 basis point decrease in the annualized nominal interest rate under the baseline calibration. Monetary policy shocks are shown to lead to strong and persistent dynamic responses of the variables under consideration. How do they compare to those estimated using structural vector autoregressive (SVAR) methods?⁹ The estimates reported by Christiano et al. (2005) indicate that the maximum output response to an identified monetary policy shock is about 0.5 percent (with 95 percent confidence interval around this point estimate of about ± 0.2). After that, output is estimated to take about one and a half years to revert to its original level. Christiano et al. (2005) also estimate a maximum investment response of about one percent (with 95 percent confidence interval around this point estimate of about ± 0.5). The estimated maximum consumption response is roughly 0.2 percent (with 95 percent confidence interval around this point estimate of about ± 0.1) while the estimated maximum

⁹It is precisely that comparison which is routinely used by proponents of NK theory to justify the quantitative relevance of this framework. See, e.g., the discussion in Galí (2015), p.68 in the context of a model featuring a constant capital stock at the firm level.

inflation response of roughly 0.2 percent (with 95 percent confidence interval around this point estimate of about ± 0.15). Finally, the nominal interest rate takes about two quarters to return half-way to its preshock level.

[Figure 2 about here]

By and large, the theoretical impulse responses shown in Fig. 2 are similar to the empirical evidence on the dynamic consequences of monetary policy shocks. An exception is investment. In fact, the (about) three percent impact response to the shock is out of line with the point estimate of one percent for the maximum response of that variable. In a way that is consistent with the large size of the investment response, the impact responses of the remaining real quantities also turn out to be somewhat to the high part of the empirically plausible range. On the positive side we can notice, however, that the impact responses of the nominal variables are better in line with corresponding point estimates of the maximum responses. We also find that the dynamic consequences of the shock are reasonably persistent. What is the relevance of this result, and what is the economic mechanism at work? Carlstrom and Fuerst (1997) show that for a constant level of net worth the agency-cost model implies a smoothing mechanism for the dynamic consequences of economic shocks that is analogous to the one implied by a convex capital adjustment cost. On the other hand, Woodford (2005) shows that a NK model featuring a convex capital adjustment cost at the firm level gives rise to a quantitatively relevant monetary transmission mechanism. In our model endogenous fluctuations in the level of entrepreneurs' net worth are limited by assuming that entrepreneurs consume a constant fraction of their net worth, and this gives rise to a quantitatively important smoothing mechanism. In order to substantiate the latter statement we shut down the financial friction by setting the bankruptcy cost, μ , to a very small value. Investment is therefore fully flexible in this case and the implied dynamic responses

of the variables under consideration to the monetary policy shock are illustrated in Fig. 3. Let us also notice that unless stated otherwise parameters σ , \bar{c}_e and ν are adjusted in such a way that the same objects as in our baseline calibration are still targeted.

[Figure 3 about here]

The results shown in Fig. 3 help explain the relevance of our baseline results. In fact, the impulse responses document the well known problem that flexible investment gives rise to counterfactual impulse responses to monetary policy shocks. This is exactly the reason why Christiano et al. (2005) and Woodford (2005) had introduced adjustment costs into the investment block of the NK framework. In their work there is, however, no empirical discipline imposed on the size of the adjustment cost, apart from a desire to parametrize the postulated cost in a way that gives rise to a realistic monetary transmission mechanism. This is true for both the investment adjustment cost in Christiano et al. (2005), as well as for the convex capital adjustment cost in Woodford (2005). On the contrary, the size of the financial friction in our model is disciplined by data on interest rate spreads, bankruptcy rates and bankruptcy costs, as explained in section 3.1. It is therefore remarkable that a financial friction of a plausible size implies a strong smoothing mechanism that makes our baseline results go a long way towards a realistic monetary transmission mechanism. Let us also notice that our model does imply impact responses to the shock (for all variables under consideration, both real and nominal) that remain within one standard deviation around the corresponding point estimates of the maximum responses in Christiano et al. (2005), if we take the freedom to disregard the empirical discipline on the financial friction under consideration and simply choose it to be sufficiently strong. It is also instructive to inspect some quantitative aspects of Fig. 3. The impact investment response to the monetary policy shock turns out to

be almost twenty percent, i.e., twenty times larger than the corresponding maximum point estimate reported by Christiano et al. (2005). In the NK lumpy investment model proposed in Reiter (2013) we found a counterfactual monetary transmission mechanism with an impact investment response of about eight percent.¹⁰ Compared with the twenty percent impact response implied by the flexible capital model we find that a standard (S,s) modelling of lumpy investment does imply a (modest) smoothing mechanism.¹¹ It is therefore reasonable to expect that a realistic modelling of lumpy investment in the context of a fully-fledged heterogeneous agent version of our model would overcome the remaining problem with a somewhat too flexible investment under our baseline calibration.

Below we inspect the robustness of our baseline results by showing the quantitative consequences of varying the model's New Keynesian features as well as the form of its financial friction in various ways. Results are reasonably robust with respect to changes in the degree of price stickiness, in the size of steady state inflation and in the size of the financial friction within an empirically plausible range. We also show that a financial friction of the exact form proposed in Carlstrom and Fuerst (1997) gives rise to a monetary transmission mechanism that is out of line with the data. Discussing the differences with respect to our baseline allows us to further inspect the economic mechanisms at work.

3.3 Robustness Analysis

The first robustness analysis regards the New Keynesian features of our model. This is illustrated in Fig. 4 and 5. In each case, our baseline results are also displayed

¹⁰This is for the case of Calvo pricing combined with (S,s) investment.

¹¹Strictly speaking, the irrelevance result in Thomas (2002) and Kahn and Thomas (2008) does therefore not go through in the context of a NK model. In fact, those authors had established an equivalence in the equilibrium determination of aggregate quantities between a (S,s) modelling of lumpy investment and a frictionless RBC model.

for comparison. The former shows the monetary transmission mechanism with price stickiness parameter θ set to 0.66. This is a typical value used in the monetary literature and corresponds to an average expected life-time of a price of 3 quarters. It is smaller than our baseline value $\theta = 0.75$.

[Figure 4 about here]

The associated consequences of the shock for the real variables thus become somewhat smaller (and hence better in line with the data) than it is the case under our baseline calibration, and the impact inflation response correspondingly increases in a way that makes it consistent with the above mentioned point estimate of the maximum inflation response in Christiano et al. (2005). We also consider the quantitative consequences of assuming zero inflation in the steady state of our model.¹² It is seen in Fig. 5 that the results are reasonably robust along that dimension.

[Figure 5 about here]

Our next robustness analysis regards size of the financial friction. More concretely, we now consider values for the bankruptcy cost, μ , that are to the high and to the low part of the empirically relevant range. This is illustrated in Fig. 6. Each line in the figure is associated with one value of $\mu \in \{0.2, 0.25, 0.36\}$.

[Figure 6 about here]

Fig. 6 brings out a clear message. Our baseline results are robust with respect to reasonable variations in the size of the financial friction. A related question regards the quantitative importance of our baseline choice for the annual risk premium in the steady state. This is addressed in Fig. 7.

[Figure 7 about here]

¹²A robustness analysis with respect to the monetary policy parameters just plays out in ways that are similar to the corresponding outcomes in standard NK models. Needless to say, those results are available upon request.

Also in this case, results are shown to be reasonably robust. It is also seen that the investment response to the shock becomes smaller if the quantitative importance of the financial friction, as measured by the risk premium, is increased. Finally, we examine the original modelling of the financial friction in Carlstrom and Fuerst (1997). In order to guarantee that the above mentioned contracting problem between entrepreneurs and the CMF is well-defined at each point in time, one has to make sure that entrepreneurs do not accumulate net worth to the point that this problem simply disappears. Carlstrom and Fuerst (1997) achieve this by assuming that entrepreneurs discount the future more heavily than do households. The entrepreneur's Euler equation is therefore of the form

$$q_t = \beta\gamma E_t \{ [q_{t+1} (1 - \delta) + r_{t+1}] roi_{t+1} \},$$

where parameter γ reflects the assumption that entrepreneurs discount the future more heavily than households. We set this parameter to 0.947. Otherwise, all parameters and steady state values are the same as in our baseline. The last equation also reflects that entrepreneurs are assumed to be risk-neutral. In our context this set of assumptions gives rise to a counterfactual monetary transmission mechanism. This is illustrated in Figure 8.

[Figure 8 about here]

In fact, the theoretical impulse responses shown in Figure 8 are out of line with their empirical counterpart. The simple economic reason is the large extent to which risk-neutral entrepreneurs engage in intertemporal consumption substitution implying highly volatile equilibrium investment dynamics. An expansionary monetary policy shock gives rise to an increase in aggregate demand in the economy. Firms are therefore incentivized to produce more and consequently increase their demand

for capital and labor. The persistent increase in the demand for capital leads to an increase in its price. The latter results in an increased return on investment which gives entrepreneurs the incentive to reduce their consumption. Starting one period after the monetary policy shock entrepreneurs increase their consumption again. The reason is that they can enjoy an increased net worth by that time, and the relative attractiveness of investing (as opposed to consuming) declines, as the dynamic consequences of the monetary policy shock start fading out. In order to eliminate this mechanism we therefore assume in the context of our baseline model that entrepreneurs consume a constant fraction of their net worth.

4 Conclusion

Once New Keynesian (NK) theory (see, e.g., Woodford 2003) is combined with a standard model of investment (see, e.g., Thomas 2002), the resulting framework loses its ability to generate a realistic monetary transmission mechanism. This is the puzzle uncovered in Reiter et al. (2013). The simple economic reason behind it is the high degree of flexibility in capital accumulation, as implied by standard investment theory. We therefore ask how to reconcile flexibility in capital accumulation with a quantitatively relevant monetary transmission mechanism. In order to address this question, we develop a NK model featuring fully flexible investment combined with a financial friction in the spirit of Carlstrom and Fuerst (1997). This simple model is shown to go a long way towards a realistic monetary transmission mechanism.

It can therefore be expected that in the presence of an empirically plausible financial friction of the type considered in this paper, standard investment theory can be integrated into an empirically relevant NK model of the monetary transmission mechanism. This is the next natural step in this agenda. The interest is twofold.

First, it is an open question whether standard normative lessons from NK theory hold up in the presence of lumpy investment. The reason is that lumpy investment is a potential source of significant heterogeneity across firms. Hence, it might play an important role in shaping the optimal monetary policy response to shocks, the same way staggered prices generate inefficient price dispersion and thus provide a motive for inflation stabilization. Sveen and Weinke (2016) make some progress on that front, however in the context of a simple Calvo (1983) style model of investment à la Sveen and Weinke (2007). Second, in order to increase the empirical relevance of the monetary transmission mechanism with respect to standard textbook treatments a rich set of additional features has been proposed. Prominent among them is an investment adjustment cost à la Christiano et al. (2005). But the existence of this adjustment cost makes NK models inconsistent with the observed lumpiness in plant-level investment. It is therefore an open question how to match the quantitative features of estimated impulse responses to a monetary policy shock without relying on assumptions that eliminate micro-level lumpiness in investment. We will address those questions relying on the method developed in Reiter (2009, 2010).

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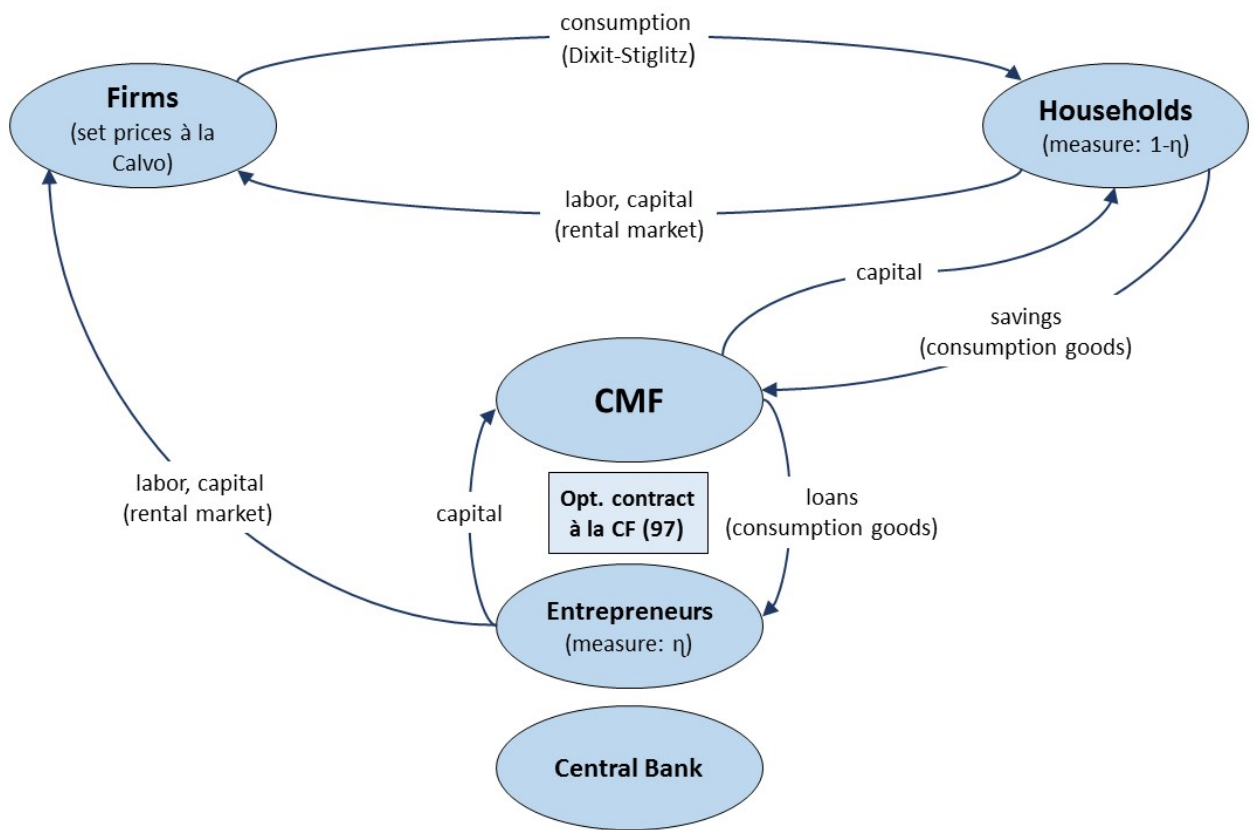


Fig. 1. A Bird's View on the Model.

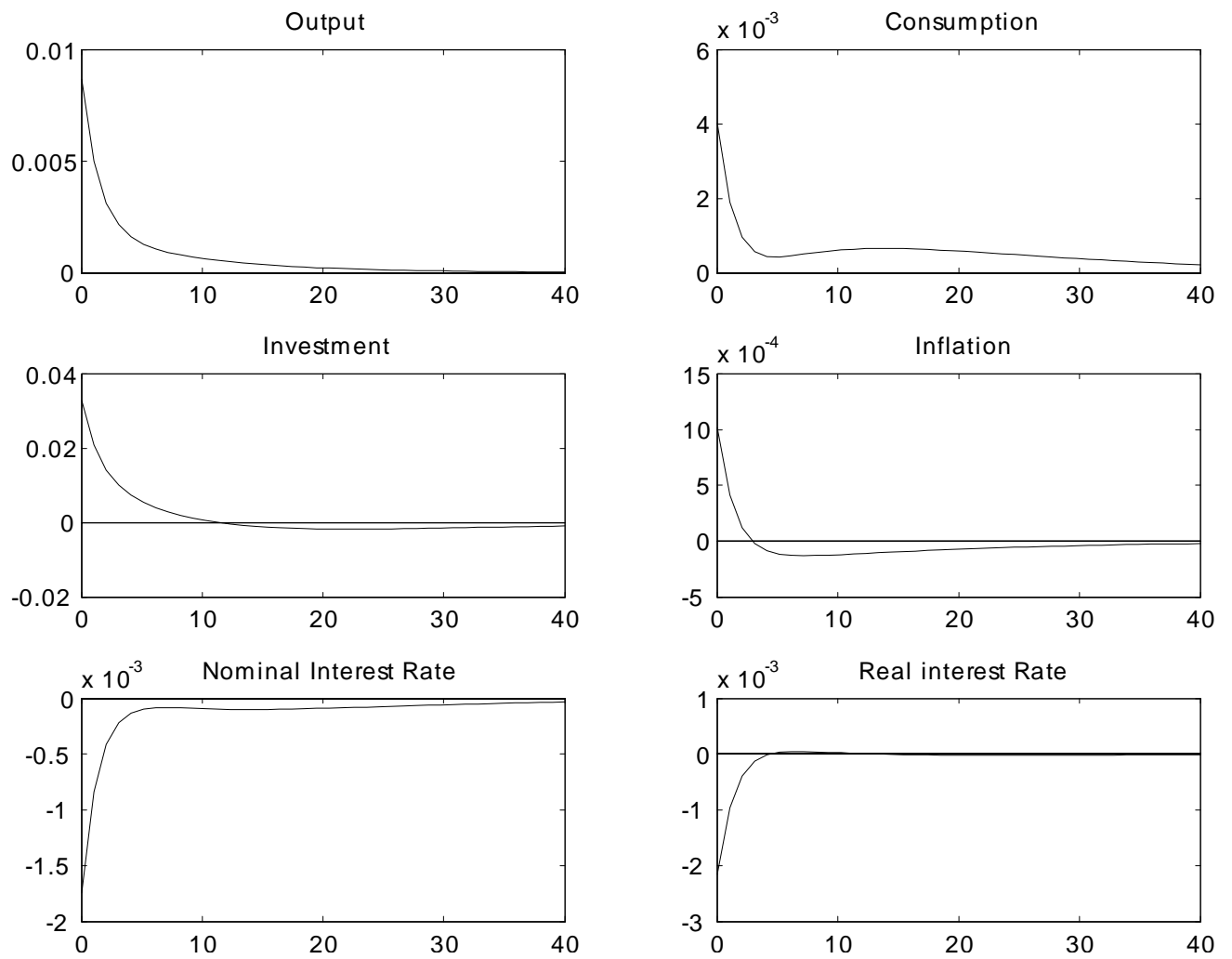


Fig. 2. Dynamic Responses to a Monetary Policy Shock: Baseline.

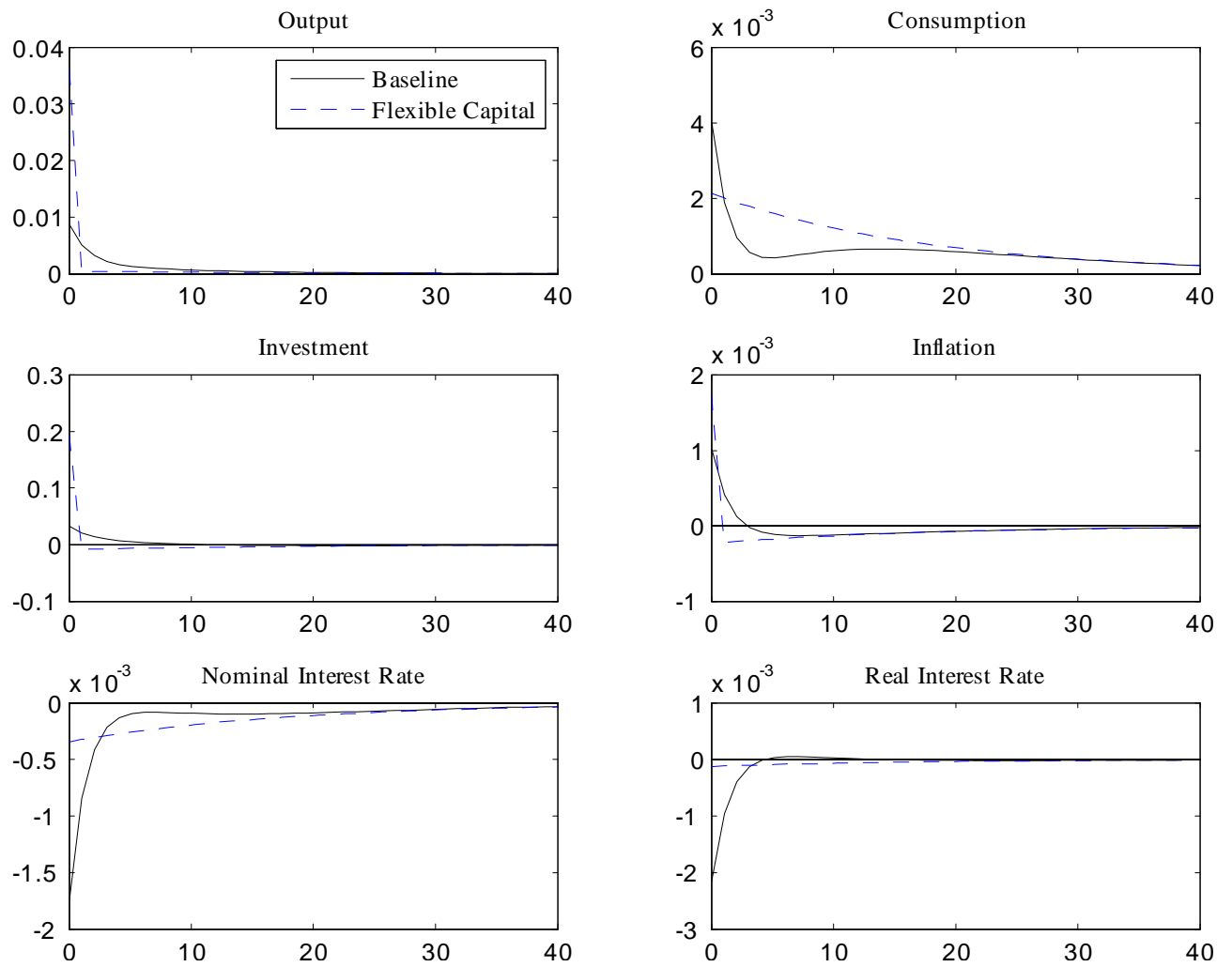


Fig. 3. Baseline vs. Flexible Capital.

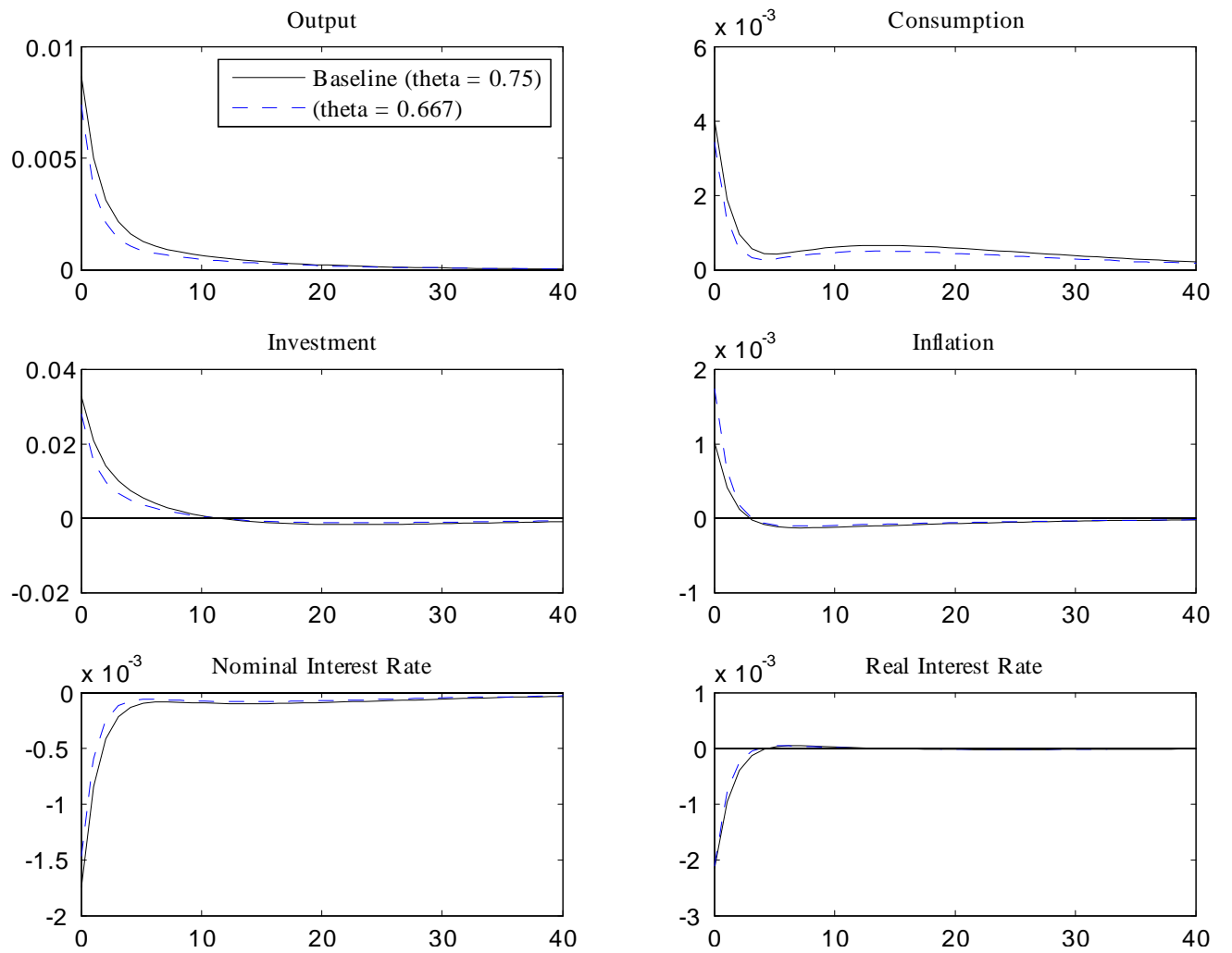


Fig. 4. Baseline vs. Low Price Stickiness.

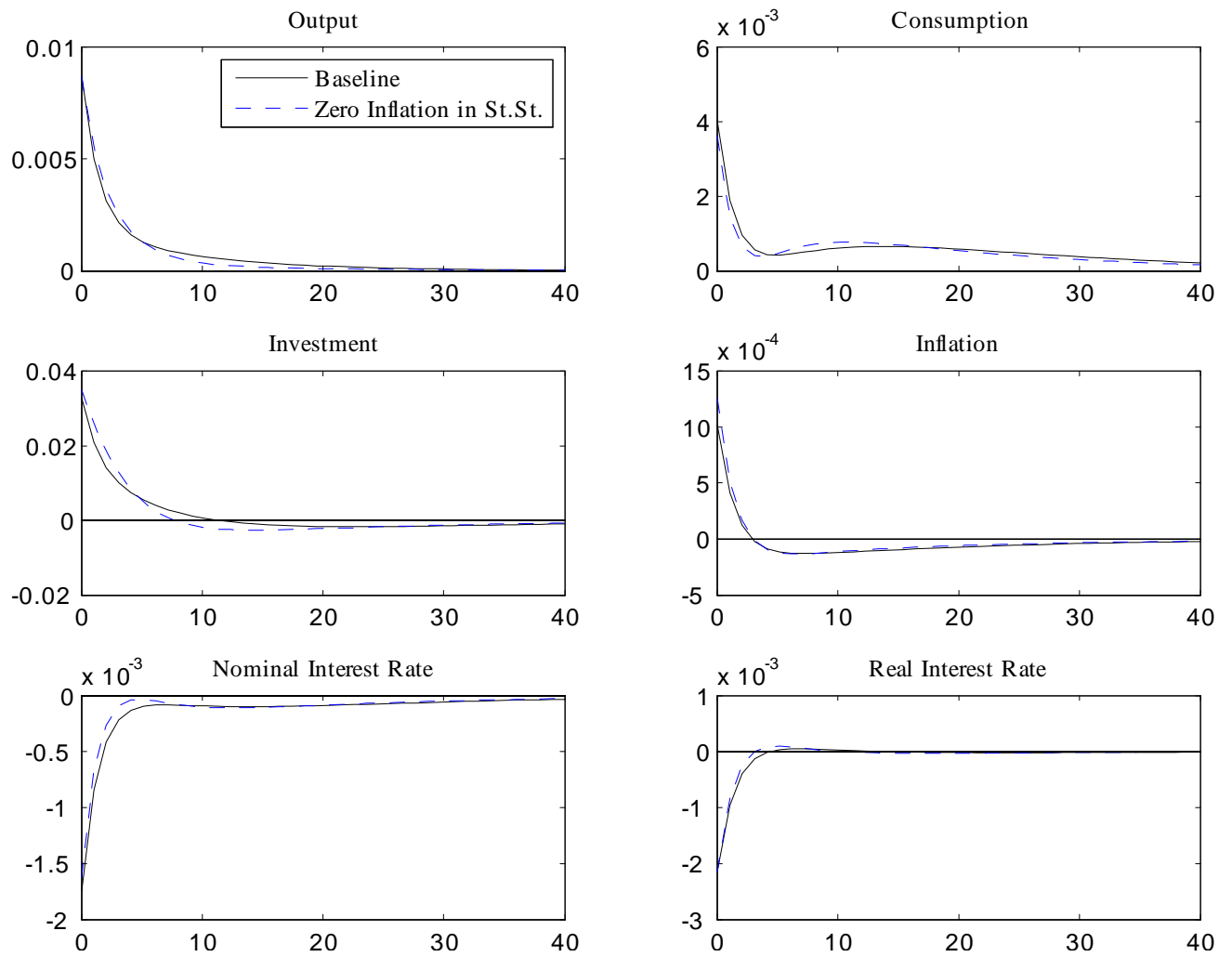


Fig. 5. Baseline vs. Zero Inflation Steady State.

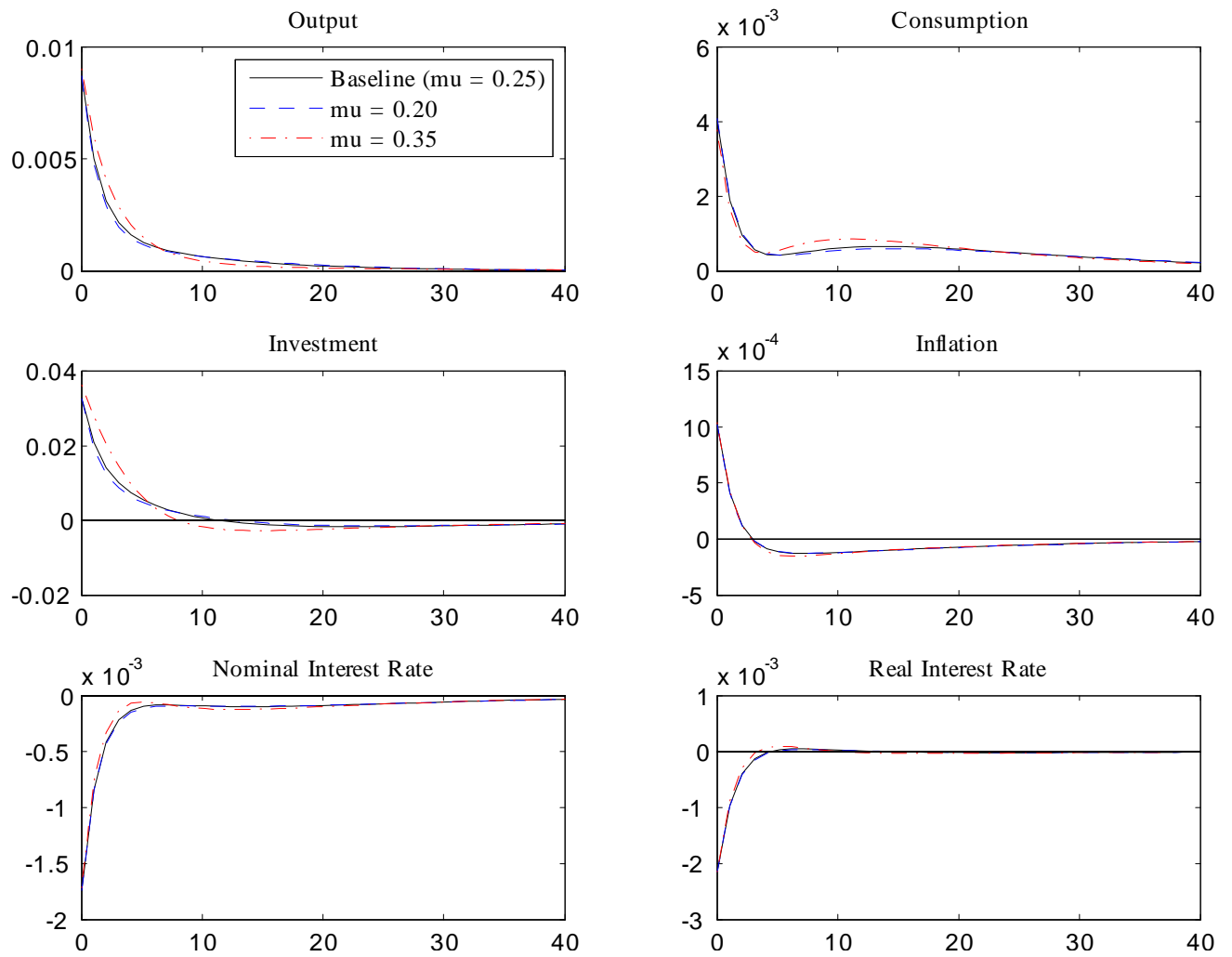


Fig. 6. Baseline vs. Alternative Bankruptcy Costs.

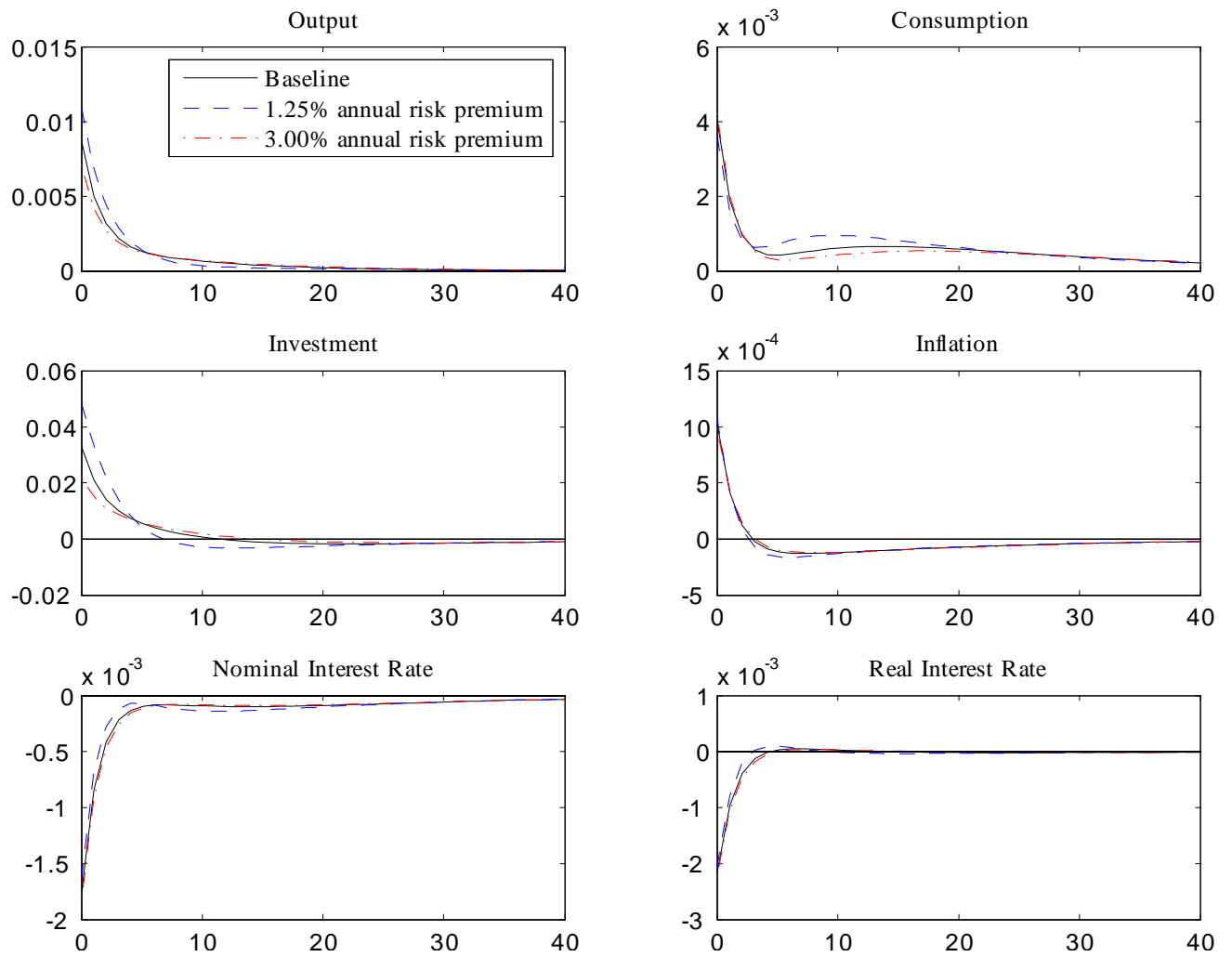


Fig. 7. Baseline vs. Alternative Risk Premia.

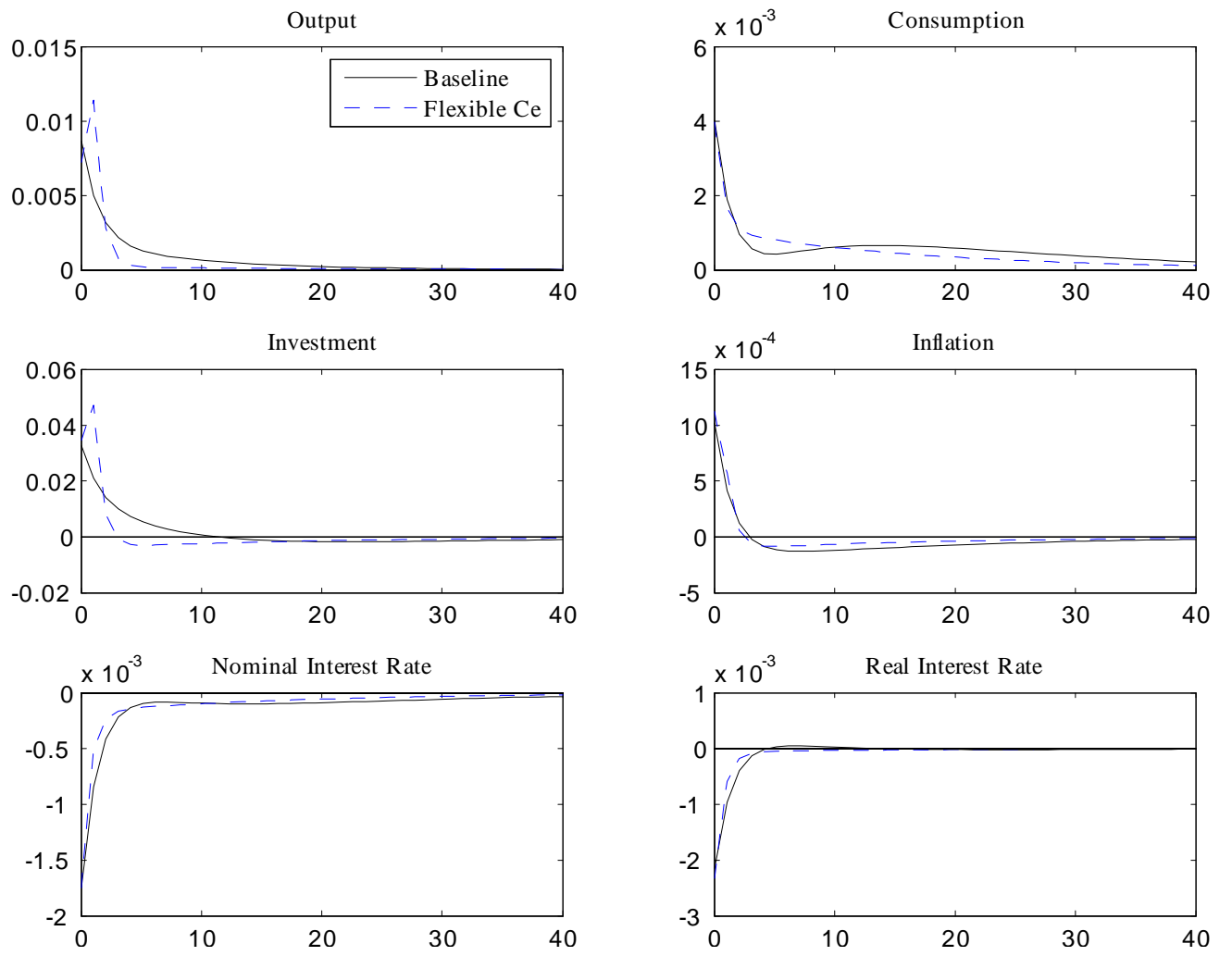


Fig. 8. Baseline vs. Carlstrom Fuerst Ass. on Entrepreneurial Consumption.