Optimal Monetary Policy, Endogenous Sticky Prices, and Multiple Equilibria

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Levon Barseghyan[*]   Riccardo DiCecio[†]

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Abstract

We analyze optimal discretionary monetary policy in an endogenous sticky prices model. Similar models with exogenous sticky prices can deliver multiple equilibria. This is a necessary condition for the occurrence of expectation traps (when private agents' expectations determine the equilibrium level of inflation). In our model, sticky-price firms are allowed to switch to flexible pricing by paying a random cost. For plausible parametrizations, our model has a unique low-inflation equilibrium. With endogenous sticky prices, the monetary authority does not validate high-inflation expectations and deviates to the Friedman rule.

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Keywords: optimal monetary policy, multiple equilibria, sticky prices.

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[*]Cornell University, e-mail: lb247@cornell.edu.

[†]FRB of St. Louis, e-mail: dicecio@stls.frb.org.

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1   Introduction

Monetary economics has recently witnessed an upsurge of interest in trying to identify the causes of the large variation in inflation across countries and time. One strand of this literature identifies expectation traps as a possible explanation. In an expectation trap scenario, the high-inflation episode of the 1970s in the US can be characterized as a period in which private agents expected high inflation. Based on these expectations, private agents took actions to shield themselves from high inflation. For example, households reduced their savings, anticipating a lower real return, and workers demanded higher nominal wages, expecting them to be worth less in real terms. The private sector's action in response to high expected inflation created a dilemma for the Fed: validate private agents' expectations and deliver high inflation or frustrate the high-inflation expectations with a tight monetary policy and accept a recession. The Fed chose the first course of action. In contrast, the 1990s can be interpreted as a period of low-inflation expectations, which determined a low level of actual inflation. In an expectation trap scenario, the lack of commitment adds to the inflation bias discussed in Kydland and Prescott (1977) and Barro and Gordon (1983) the costs of high and variable inflation driven by expectations, independently from economic fundamentals.

A necessary condition for expectation traps to exist is multiplicity of equilibria. Albanesi et al. (2003) use a cash-credit goods model à la Lucas and Stokey (1987) to show that multiple equilibria are possible in a no-commitment optimal monetary policy framework. The key assumption behind the multiplicity of equilibria is that some firms cannot adjust their prices in response to changes in monetary policy. In this paper we relax this assumption. We argue that if sticky-prices firms are allowed to pay menu costs to reoptimize, such costs have to be implausibly high to support multiple equilibria.

In Albanesi et al. (2003) the monetary authority is benevolent, and weighs the benefits and costs of inflation, maximizing the utility of the representative agent. Firms have market power and produce an inefficiently low level of output. Some firms are assumed to set their prices before the monetary authority's actions. The monetary authority has an incentive to generate inflation to increase output, forcing sticky-price firms to produce more. The marginal benefit of inflation is roughly constant across inflation levels. The representative household faces a cash-in-advance constraint on some of the goods it purchases. In order to buy cash goods it has to hold money and give up the interest it could earn from buying bonds. A positive interest rate distorts the allocation between cash and credit goods. The marginal cost of

inflation can be lower than the marginal benefit both for low and high values of inflation. This can generate multiple equilibria. Albanesi et al. (2003) illustrate this possibility with numerical examples.

The assumption that some firms cannot protect themselves in any way from the monetary authority's actions is reasonable for economies with low and stable inflation. With high and volatile inflation, firms have strong incentives to revise their prices. We allow sticky-price firms to revise their prices by paying a random fixed cost.[1] Firms with a cost lower than the expected gain will revise their price. If it is so costly to revise prices that no firm would do so, independently of the monetary authority's actions, our model simplifies to the model of Albanesi et al. (2003).[2]

In our model, in a candidate equilibrium, sticky- and flexible-price firms post the same price. Hence, in a candidate equilibrium, sticky-price firms do not revise their price even if they have a chance to do so and the degree of price stickiness in our economy is the same as in Albanesi et al. (2003). However, off equilibrium, sticky-price firms have incentives to revise their price by paying a menu cost. This opens the door to a profitable deviation for the government from the supposed equilibrium. By deviating to the Friedman rule, the monetary authority can eliminate the distortion between cash and credit goods. At the same time, the relative price of sticky-price goods is high. If sticky-price firms cannot protect themselves from the monetary authority's deviation, the distorted allocation between flexible- and sticky-price goods makes the deviation to the Friedman rule too costly, and the high-inflation is indeed an equilibrium. If enough sticky-price firms would reoptimize in response, the cost of deviating to the Friedman rule, and distorting the allocations across sticky- and flexible-price goods, is smaller than the gain. In this case our model has a unique low-inflation equilibrium.

For the high-inflation equilibrium to exist under the benchmark parametrization of Albanesi et al. (2003), about ten percent of firms in our economy should have menu costs such that they would not change their price even for a 3,650 percent increase in profits. For the parametrization most favorable to the existence of multiple equilibria, the high-inflation equilibrium can be supported if 7 percent of all firms have menu costs that would prevent them from repotimizing when facing a three-fold increase in their profits. Menu costs this large are orders of magnitude greater than what empirical work

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[1]Several authors have studied models with state-dependent pricing. See, for example, Ireland (1997), Dotsey et al. (1999), and Burstein (2006).

[2]If it is so cheap to revise prices that all firms do, our model boils down to a flexible prices model.

suggests.[3]

In a related paper Siu (2006) endogenizes sticky prices in the model of King and Wolman (2004)[4] and reaches similar conclusions. With reasonable price-revision costs and small inflation costs unrelated to price stickiness,[5] there is a unique low-inflation equilibrium.

Section 2 describes the model with endogenous sticky prices. In Section 3 we explore the properties of our models with numerical examples. We perform sensitivity analysis in Section 4. Section 5 concludes.

2   The Model

In this section we present the economy's environment, we describe the agents' problems, and we define and characterize equilibria.

2.1   Environment

Our model is populated by households, firms, and a monetary authority. There is a continuum of firms, each one producing a variety of goods as a monopolist.

The timing is as follows:

- a fraction μ of firms set their prices (P^e is the average price chosen);

- the monetary authority chooses its policy to maximize the utility of the representative household;

- each sticky-price firm draws a realization of the adjustment cost from a uniform distribution, $U_{[0,b]}$;

- each sticky-price firm decides whether to revise its price by comparing the cost and the benefit;

- all the remaining private decisions are made.

The state of the economy, from the monetary authority's perspective, is given by the average price level set by the sticky-price firms. The money

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[3]See Levy et al. (1997) and Bils and Klenow (2004).

[4]See King and Wolman (2004) for a discussion of the differences between their model and Albanesi et al. (2003).

[5]Due to the difference in timing, in our model inflation is costly independently of the degree of price rigidity.

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growth rate is denoted by x and the corresponding policy rule by $X(P^e)$. The state of the economy, after the monetary authority decision and the realization of the policy, shock is (P^e, x).

2.2 Households

The representative household solves the following problem:

$$\max \sum_{t=0}^{+\infty} \beta^t u(c_t, n_t), \ 0 < \beta < 1, \ \sigma > 0, \ \psi > 0, \tag{1}$$

$$u(c_t, n_t) = \frac{\left[c_t(1-n_t)^\psi\right]^{1-\sigma}}{1-\sigma}, \ c_t = \left[\int_0^1 c_t(\omega)^\rho \, d\omega\right]^{\frac{1}{\rho}}, \ \rho \in (0,1), \tag{2}$$

where c_t denotes aggregate consumption, composed of individual consumption goods $c_t(\omega)$ aggregated according to (2), and n_t denotes hours worked. The parameter ρ pins down the elasticity of substitution between individual goods, $\frac{1}{1-\rho}$. The preferences parameters have the usual interpretation: β is the discount factor, ψ is a scale parameter pinning down the hours worked-to-leisure ratio in equilibrium, and σ is the coefficient of relative risk aversion.

The household faces the following constraints[6]:

$$c_t(\omega) \geq 0 \ \forall i, \ 0 \leq n_t \leq 1, \tag{3}$$

$$M + B \leq A, \tag{4}$$

$$P^e \mu_1 z c_{11} + \hat{P}(1-\mu_1) z c_{12} \leq M, \tag{5}$$

$$xA' + z\left[P^e \mu_1 c_{11} + \hat{P}(1-\mu_1) c_{12}\right] + (1-z)\left[P^e \mu_2 c_{21} + \hat{P}(1-\mu_2) c_{22}\right] \leq$$
$$Wn + RB + M + (x-1) + D + T. \tag{6}$$

Here, z is the fraction of cash goods, c_{11} and c_{12} are the quantities of cash goods purchased from sticky- and flexible-price firms, c_{21} and c_{22} are the quantities of credit goods purchased from sticky- and flexible-price firms. The measures of sticky-price firms producing cash goods and credit goods are denoted by μ_1 and μ_2, respectively. The aggregate nominal stock of money at the beginning of each period is normalized to 1. The household

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[6] All nominal variables are scaled by the aggregate money supply; A' is scaled by next period's aggregate money supply.

can split its assets, A, into money and bonds — M and B, respectively. The gross nominal interest rate is denoted by R and the money growth rate by x. Constraint (5) states that, in order to buy cash goods, the household has to hold cash. Inequality (6) is the budget constraint. The-left hand side represents expenses for buying assets and goods. The right-hand side represents the household's revenues, stemming from labor income, interest on bonds, beginning of period's money, injections of money from the government, dividends from firms, and lump-sum taxes (transfers) from the government.

The household's problem can be restated in a functional equation form as:

$$v\left(A, P^e, x\right) = \max_{n, M, A', \{c_{i,j}\}_{i,j=1,2}} u\left(c, n\right) + \beta v\left(A', P^{e\prime}, X\left(P^e\right)\right) \qquad (7)$$

The first-order conditions for the household's problem are:

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\begin{aligned}
\frac{u_{11}}{u_{12}} &= \frac{\mu_1}{1-\mu_1}\left(\frac{c_{11}}{c_{12}}\right)^{\rho-1} = \frac{\mu_1}{1-\mu_1}\frac{1}{q} \\
\frac{u_{21}}{u_{22}} &= \frac{\mu_2}{1-\mu_2}\left(\frac{c_{21}}{c_{22}}\right)^{\rho-1} = \frac{\mu_2}{1-\mu_2}\frac{1}{q} \\
\frac{u_{11}}{u_{21}} &= \frac{\mu_1}{\mu_2}\frac{z}{1-z}\left(\frac{c_{11}}{c_{21}}\right)^{\rho-1} = \frac{\mu_1}{\mu_2}\frac{z}{1-z}R \qquad (8)\\
\frac{u_{11}}{u_{22}} &= \frac{1-\mu_1}{1-\mu_2}\frac{z}{1-z}\left(\frac{c_{12}}{c_{22}}\right)^{\rho-1} = \frac{1-\mu_1}{1-\mu_2}\frac{z}{1-z}R \\
\frac{-u_n}{u_{22}} &= \frac{\psi}{(1-n)(1-z)(1-\mu_2)c^{-\rho}c_{22}^{\rho-1}} = \frac{\theta\rho}{(1-\mu_2)(1-z)} \\
&\frac{xu_{22}}{P^e(1-\mu_2)(1-z)} = \beta v_1\left(1, P^{e\prime}, X\left(P^{e\prime}\right)'\right),
\end{aligned}
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where u_{ij} denotes the partial derivative of u with respect to c_{ij}, u_n denotes the partial derivative of u with respect to n, and v_1 denotes the partial derivative of v with respect to its first argument.

The cash-in-advance constraint can be rewritten as $zP^e\left[\mu_1 c_{11} + (1-\mu_1)c_{12}\right] \leq 1$, and it is binding for $R > 1$:

$$\{1 - zP^e\left[\mu_1 c_{11} + (1-\mu_1)c_{12}\right]\}(R-1) = 0. \qquad (9)$$

2.3   Firms

Each firm $\omega \in (0,1)$ has a production function $y\left(\omega\right) = \theta n\left(\omega\right)$, where $n\left(\omega\right)$ is employment and θ represents the marginal productivity of labor. Firms set

prices as mark-ups over marginal costs:

$$P^e = \frac{W\left(P^e, X\left(P^e\right)\right)}{\theta\rho}, \tag{10}$$

$$\hat{P} = \frac{W\left(P^e, x\right)}{\theta\rho}. \tag{11}$$

Profits are given by:

$$\pi_{11} = P^e c_{11} - \frac{W}{\theta} c_{11} = (1-\rho) P^e c_{11},$$

$$\pi_{12} = (1-\rho)\hat{P}c_{12}, \ \pi_{21} = (1-\rho) P^e c_{21}, \ \pi_{22} = (1-\rho)\hat{P}c_{22}.$$

The gain for sticky-price firms from revising their price is:

$$\eta_i = \pi_{i2} - \pi_{i1}, \ i = 1, 2.$$

All firms for which the realized cost is smaller than η_i will revise their price. The marginal cash-good and credit-good firms revising their price are determined by $\hat{\mu}_i = \min\left[\eta_i/b, \mu\right] \ i = 1, 2$. The number of sticky-price firms will be given by the fraction of firms that were sticky minus those who choose to adjust their price:

$$\mu_i = \mu - \hat{\mu}_i, \ \ i = 1, 2. \tag{12}$$

2.4   Monetary Authority

The monetary authority chooses the current money growth rate, x, taking as given future monetary policies and the private sector allocations, in order to maximize the representative household's utility:

$$\max_{x \in [\beta, \bar{x}]} v\left(1, P^e, x\right), \tag{13}$$

where $v\left(.\right)$ is the household's value function.

2.5   Government

The government runs a balanced budget by financing exogenous public spending, g, with lump sum taxes, $\tau = g$. Furthermore, the government rebates the price revision costs (collected from sticky-price firms choosing to reoptimize) to the households in a lump sum fashion.

2.6 Equilibria

Definition 1 *A private sector equilibrium, given a monetary policy rule $X(P^e)$ and a current money growth rate x, is a collection of functions P^e, $\hat{P}(P^e, x)$, $W(P^e, x)$, $v(A, P^e, x)$, $n(A, P^e, x)$, $c_{ij}(A, P^e, x)$ $j, i = 1, 2$, $M(A, P^e, x)$, $A'(A, P^e, x)$, $R(P^e, x)$ such that:*

- *n, M, A', $\{c_{i,j}\}_{i,j=1,2}$ solve the household's problem (7);*

- *firms optimize, i.e., they set prices according to (10) and (11);*

- *the number of sticky-price firms is determined by (12);*

- *markets clear:*

$$A'(1, P^e, x) = 1, \quad M(1, P^e, x) = 1,$$
$$g + z\left[\mu_1 c_{11} + (1 - \mu_1) c_{12}\right] + (1 - z)\left[\mu_2 c_{21} + (1 - \mu_2) c_{22}\right] = \theta n.$$

Definition 2 *A Markov equilibrium is a private sector equilibrium and a monetary policy rule such that $X(P^e)$ solves (13).*

2.6.1 Characterizing Equilibria

The policy can be characterized as a choice of the price of credit goods $\hat{P}$, or equivalently of the relative price $q = \frac{\hat{P}}{P^e}$, rather than a choice of the money growth rate x.[7] Since q does not affect future allocations, the monetary authority faces a static problem:

$$\max_q \frac{\left[c(1 - n)^\psi\right]^{1-\sigma}}{1 - \sigma}. \tag{14}$$

A Markov equilibrium corresponds to $P^e = \hat{P}$, or equivalently to $q = 1$. Notice that, as in Albanesi et al. (2003), the first-order conditions to (14) are only necessary for an equilibrium. In practice, the monetary authority objective function has to be checked globally to rule out possible profitable deviations from the candidate equilibria identified by the first-order conditions.

Our model boils down to the model of Albanesi et al. (2003) for $b \to +\infty$, i.e., $\mu_1 = \mu_2 = \mu$ $\forall q$. If it is prohibitively costly to revise prices,

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[7]Alternatively, policy can be characterized as a choice of the nominal interest rate R as in Albanesi et al. (2003).

no firms choose to do so, and the degree of price stickiness can be thought of as exogenous. For $b \to 0$ our economy has flexible prices and a unique equilibrium in which the Friedman rule is the optimal policy.

The profit differentials can be expressed as[8]:

$$\eta_1 = \frac{1-\rho}{z} \frac{q^{\frac{1}{\rho-1}} - 1}{\mu_1 + (1-\mu_1) q^{\frac{\rho}{\rho-1}}},$$

$$\eta_2 = R^{\frac{1}{1-\rho}} \eta_1.$$

In equilibrium, sticky- and flexible-price firms make the same profits: $\eta_2|_{q=1} = \eta_1|_{q=1} = 0$. Thus in internal equilibria, no firms will choose to revise their prices and $\mu_1 = \mu_2 = \mu$.

For $q \neq 1$, monetary authority decisions can induce positive profits differential and affect the degree of price stickiness in the economy. Credit-goods firms with sticky prices have a bigger incentive to reoptimize, since they face a higher demand, which is positively related to the interest rate ($R \geq 1$), i.e., $\eta_2 \geq \eta_1$. This implies that more credit-goods firms revise their price ($\hat{\mu}_2 \geq \hat{\mu}_1$) and that the degree of price stickiness is lower for credit-goods producers ($\mu_2 \leq \mu_1$).

The candidate equilibria in our model for $b \in (0, +\infty)$ are different from those in the model of Albanesi et al. (2003). The monetary authority takes into account the effect of its decision on the degree of stickiness in the economy. In particular, this affects the possibility of profitable deviations. We illustrate this point in the following section.

3 Computing Equilibria

In this section we explore the properties of our model for intermediate values of b using numerical examples and perform sensitivity analysis.

We compute the equilibria, setting the fraction of credit goods, the upper bound on the fraction of sticky-price firms, productivity, government spend-

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[8]In percentage terms the profit differentials are the same for cash- and credit-goods firms:

$$100 \frac{\eta_1}{\pi_{11}} = 100 \frac{\eta_2}{\pi_{21}} = 100 \left(q^{\frac{1}{\rho-1}} - 1 \right).$$

z	μ	θ	g	ρ	ψ
0.15	0.1	1	0.05	0.45	1

Table 1: Benchmark model: parameter values.

ing,[9] and the utility parameters[10] to the same values as in Albanesi et al. (2003), reported in Table 1.

Figure 1 portrays the monetary authority's objective function for the low-inflation candidate equilibrium, as a function of b and q. Notice that for any b, the maximum utility is achieved for $q = 1$. In words, in our model the low-inflation candidate equilibrium is indeed an equilibrium. Changes in b have a second-order effect on the allocations (see Figure 2).

Figure 3 shows the utility surface corresponding to the high-inflation candidate equilibrium. For any b, a local maximum is achieved at $q = 1$. Again, the allocations for corresponding to $q = 1$ do not change much as b decreases (Figure 4). However, for a sufficiently small b, the monetary authority's ability to tinker with the economy's degree of stickiness generates a profitable deviation. Playing the lowest possible q compatible with the non-negativity constraint on the interest rate delivers a higher utility than at the local optimum $q = 1$. That is, for a low enough b the high-inflation candidate equilibrium is no longer an equilibrium. Figure 5 compares the allocations at the local maximum $q = 1$ (gray dotted lines) with the allocations at the global maximum (solid black lines), as functions of b. For $b < b^* = 25,375.39$, the endogeneity of sticky prices induces a profitable deviation. Notice that the deviation involves lowering the interest rate as much as possible ($R = 1$). When the government deviates to the Friedman rule, it increases the relative price of sticky-price goods, i.e. lowers q. The benefit of such a deviation is the elimination of the distortion between cash and credit goods and does not depend on b. The cost, which is the distortion between sticky and flexible firms, declines as b declines. The lower b is, the higher the fraction of firms that reset their prices and the lower the fraction of firms that produce at highly inefficient levels.

At b^*, around 1 percent of the firms which originally had sticky prices pay the price-revision cost and switch to flexible pricing. The gains from resetting prices will be 3,650 percent increase in profits. In order to sustain the high-

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[9]Notice that normalizing θ to 1 makes it a superflous parameter. Also, setting government spending to zero would have minor effects on all the results. The only reason we retain these parameters is for ease of comparison with Albanesi et al. (2003).

[10]Given the static nature of problem (14), σ does not affect any of the results. We chose $\sigma = 0$ in what follows.

inflation equilibrium, the distribution of the menu costs should be such that 99 percent of the sticky-price firms have menu costs higher than 3,650 percent of their profits. To put these numbers in perspective, note that Levy et al. (1997) put the average cost of price adjustment for U.S. supermarket chains to 0.7 percent of revenues, while the calibration of the menu cost function in Golosov and Lucas (2007), based on Klenow and Kryvstov (2005), implies that the average cost of price adjustment is 0.5 percent of total revenues.

4   Sensitivity Analysis

In this section we explore how b^* and the corresponding degree of price stickiness change as μ (the initial degree of price stickiness) and z (the fraction of cash goods) vary. We consider the two values of z in Albanesi et al. (2003). For $z = 0.13$ the range of μ for which the exogenous sticky prices model admits multiple equilibria is $[0.086, 0.135]$; the corresponding range of μ for $z = 0.15$ is $[0.0993, 0.129]$.

Figure 6 displays b^*, the lowest value of b for which the high-inflation candidate equilibrium is an equilibrium, as a function of the initial measure of sticky-price firms for the two values of z we consider. The higher is the initial degree of price stickiness in our model, the more robust is the high-inflation candidate equilibrium. For the highest values of μ for which the high-inflation equilibrium exists, the value of b^* is 123, for $z = 0.15$ and 108, for $z = 0.13$. At these values of b^* the government is indifferent between deviating to Friedman rule or validating the expectations and delivering $q = 1$. The gains for sticky-price firms from resetting their prices remain extremely high (see Figure 7): about 264 percent (if $z = 0.15$) and 300 percent (if $z = 0.13$).

Figure 8 displays the degree of price stickiness that the monetary authority's deviation from the high-inflation candidate equilibrium would induce. The higher μ is, the lower the degree of stickiness associated to a profitable deviation. In order for the high-inflation candidate equilibrium to be an equilibrium the distribution of menu costs should be such that at least 7 (8.3) percent of all firms in the economy face a menu cost higher 300 (264) percent of their profits for $z = 0.13$ ($z = 0.5$). These values are orders of magnitude higher then those estimated by Levy et al. (1997) or inferred by Golosov and Lucas (2007).

5   Conclusions

The expectation traps hypothesis has been advocated in the literature as
a possible explanation for episodes of high inflation. Albanesi et al. (2003)
present a model where the expectation trap is sprung by sticky-price firms
posting high prices because of high expected inflation. We generalize their
model by allowing sticky-price firms to revise their price in response to the
monetary authority's action by paying a menu cost. For reasonable parame-
trizations, our model has a unique low-inflation equilibrium.

In response to high inflation, lowering the interest rate would eliminate
the distortion between cash and credit goods. In Albanesi et al. (2003) sticky-
price firms would remain stuck with high prices and the resulting distortion in
the allocations is so costly as to support a high-inflation equilibrium. In our
model, the allocation distortion cost is undone by sticky-price firms becoming
flexible pricers and deviating to the Friedman rule is optimal.

In our model, the possibility for firms to protect themselves against high
inflation by revising their pricing decision unwinds the expectation trap. This
rules out episodes of high inflation driven by non-fundamental uncertainty.
However, the lack of commitment is still costly because it induces the mon-
etary authority to deliver higher-than-optimal inflation.

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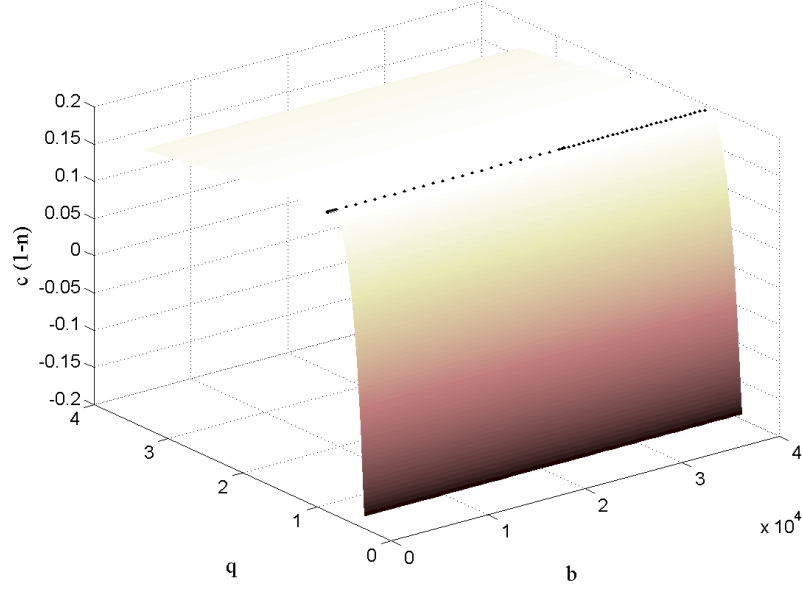
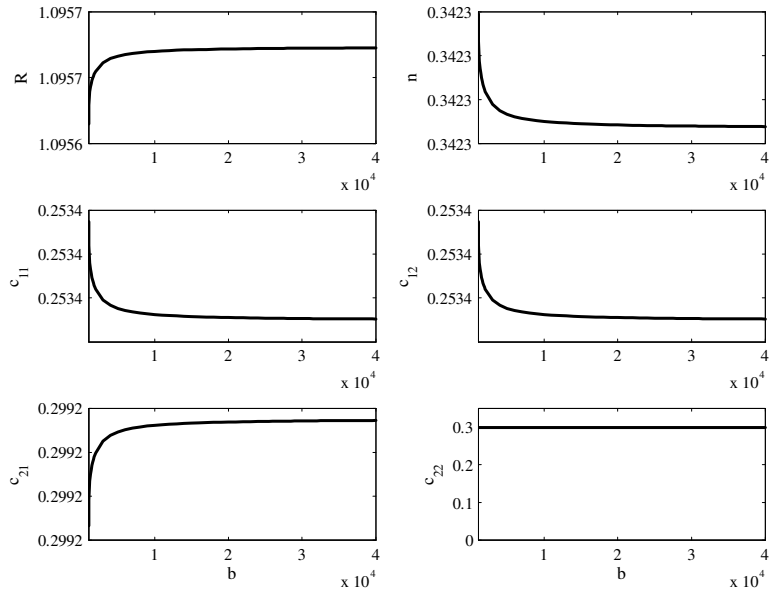Figure 1: Monetary authority's objective function in the low-inflation equilibrium.

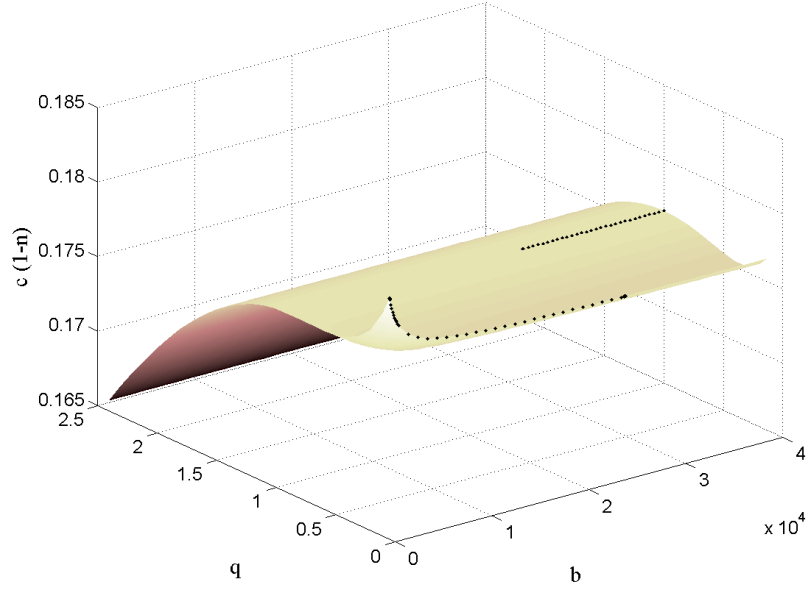Figure 2: Allocations in the low-inflation equilibrium.

Figure 3: Monetary authority's objective function in the high-inflation candidate equilibrium.
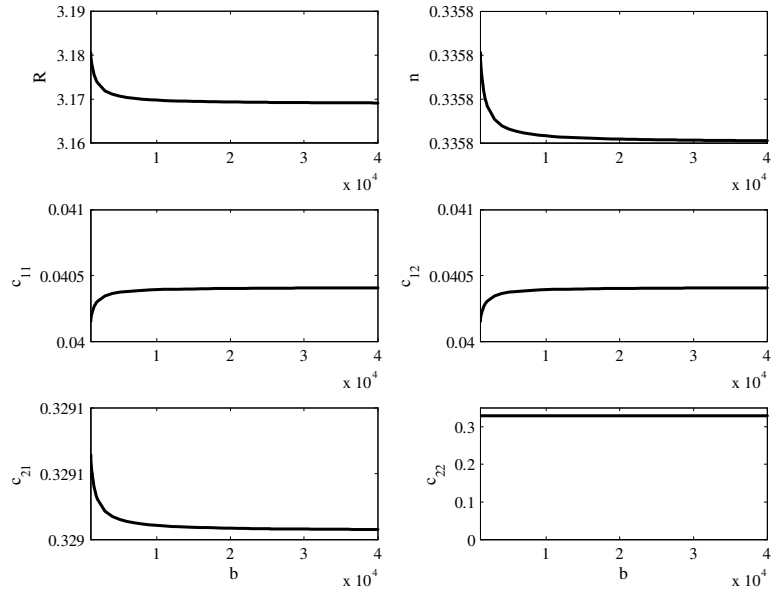
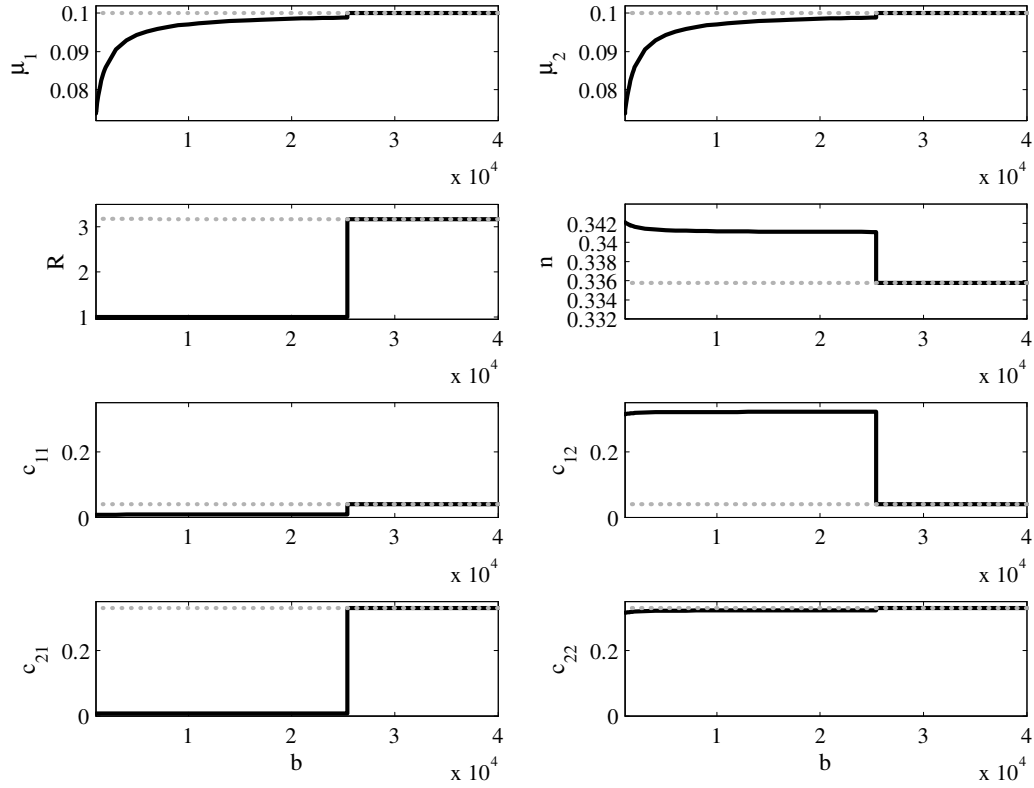Figure 4: Allocations in the high-inflation candidate equilibrium.

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Figure 5: Allocations in the high-inflation candidate equilibrium (gray) and allocations corresponding to the maximum utility for the monetary authority (black).
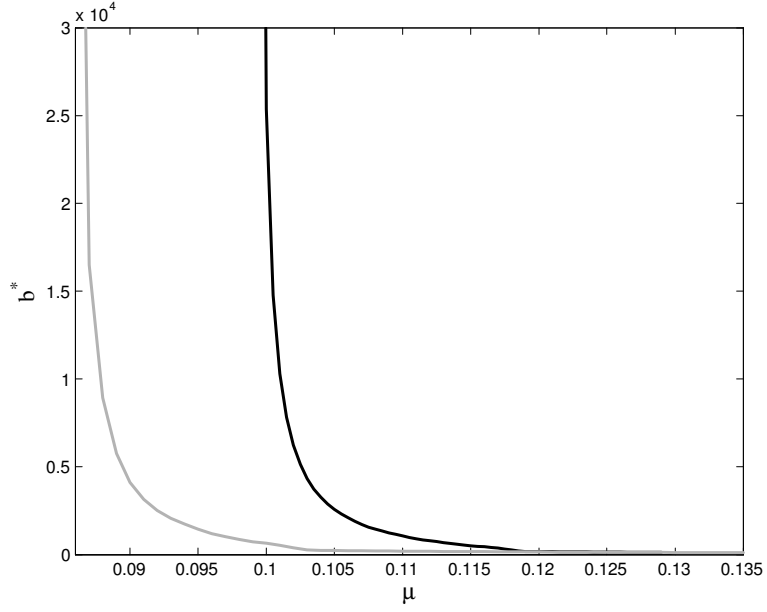
Figure 6: Minimum level of the upper bound of the price revision distribution consistent with multiple equilibria: $z = 0.13$ (gray) and $z = 0.15$ (black).
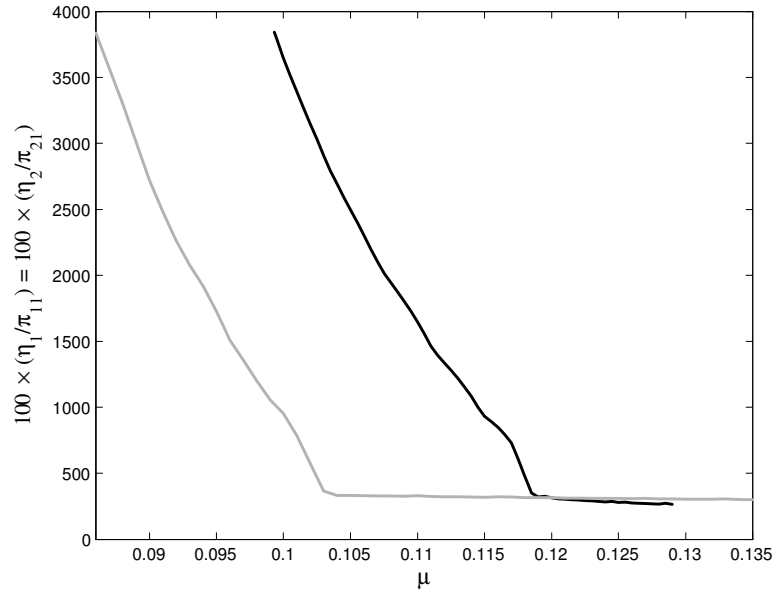

Figure 7: Profit differential in percentage for the marginal price-revising firm at b^*: $z = 0.13$ (gray) and $z = 0.15$ (black).
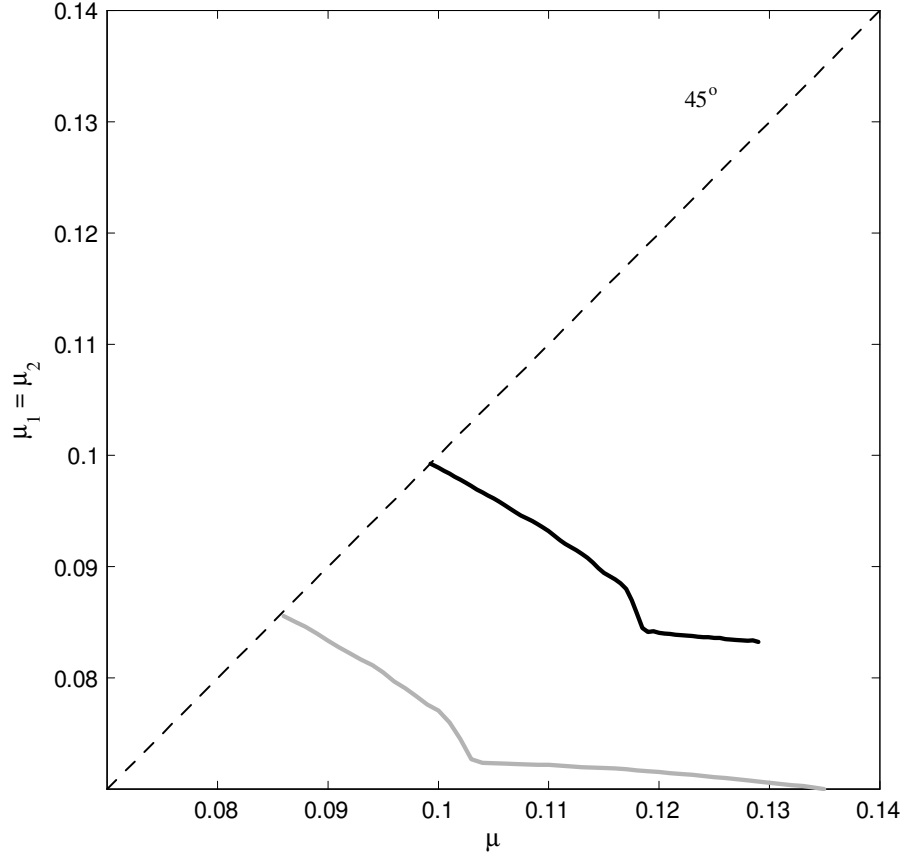
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Figure 8: Degree of price stickiness corresponding to a monetary authority's deviation from the high-inflation candidate equilibrium: $z = 0.13$ (gray) and $z = 0.15$ (black).