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Optimal State-Dependent Rules, Credibility, and Inflation Inertia[*]

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1. Introduction

It is largely believed that nominal rigidities have important consequences for the effects of monetary policy. In particular, those rigidities could explain the reluctance of inflation to respond to monetary stabilization policies. Indeed, the view that intermittent and discontinuous staggered adjustment of individual prices is the ultimate cause of inflation inertia became prevalent among New Keynesian economists[1].

We examine inflation inertia in a model where pricing rules are optimal and individual prices are rigid. Furthermore, we investigate the relationship between credibility and disinflation costs. We claim that preceding work on the importance of nominal rigidities for disinflation costs uses a framework which is inappropriate. The assumption of a given pricing rule, which does not respond to changes in monetary policy is not innocuous[2]. As we show, the interaction between optimal pricing rules and credibility is essential in the determination of the costs of disinflation. As a result, substantial inflation inertia is generated only when credibility is low.

The optimal pricing policies in our model are state dependent[3]. The literature

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[1] Taylor (1983) is an important earlier work.

[2] This criticism applies to most of the literature. The exception is Tsiddon (1991), who analyzes the instantaneous effect of a credible inflation reduction, when pricing policies are one-sided Ss rules.

[3] Barro (1972) and Sheshinski and Weiss (1977, 1983) are pioneer works on the derivation of optimal state-dependent rules under menu costs.

on the costs of disinflation engendered by inflation inertia has until now used mainly time-dependent pricing policies (Taylor 1983, Ball 1994,1995, Ireland 1995)[4]. In those models each individual price is fixed for a preset amount of time. In this setting, whatever happens during the period in which a price is fixed cannot affect individual behavior, even a drastic change in the policy environment. This ad-hoc unresponsiveness of individual prices is the mechanism through which disinflation can be made costly in this setting[5]. Since the rules are not optimally derived, they are kept invariant to the changes in monetary policy, even the credible ones.

By contrast, when rules are state-dependent, price rigidity does not imply that an individual price is fixed at any moment, notwithstanding what happens in the environment. A price is fixed only to the extent that the optimal price is not driven too far away from it. Moreover, optimal state-dependent pricing rules are affected by the credibility of monetary policy. We believe that those features make optimal state-dependent rules a much better description of individual behavior in the context of a changing policy environment.

We model nominal rigidity as resulting from a fixed cost of changing prices, often referred as menu costs in the macroeconomic literature. Although we consider the explanation for such adjustment costs as a missing foundation in our model, pricing behavior of firms in inflationary economies has been shown to be consistent with predictions from a model at which optimizing pricing setters face menu costs, as we discuss in section 6.3.1. Therefore, we consider the modelling of the change in behavior of such agents when responding to monetary policy shifts, as a method which yields invaluable insights on the mechanics of monetary based disinflations.

Non-credible disinflations can be actually costly in an model with state-dependent rules. However, the mechanism is entirely different from the one that renders disinflation costly in a time-dependent model. As it will be shown, an inflationary economy is characterized by an asymmetric distribution of deviations of individual prices from optimal ones. That is, there is always a much larger number of firms with prices substantially lower than the optimal than firms with prices higher than the optimal. As money growth is stalled, this asymmetry interacts with symmetric idiosyncratic shocks to produce inflation persistence: the symmetric idiosyncratic shocks trigger more upward than downward adjustments. This effect was mentioned by Caballero and Engel (1992), but they did not pursue the issue further[6].

When the policy is credible, the change of policy rules results in a narrower inaction range, specially for positive price deviations. Therefore, a substantial number of units are caught with price deviations that exceed the upper bound of the new inaction range, triggering a substantial amount of instantaneous downward adjustments[7]. As

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[4] Again, the exception is Tsiddon (1991). Bonomo and Garcia (94), Fischer (86) and Simonsen (83) use rules that include indexation. However, the moment of indexed adjustment is predetermined.

[5] Still, credibility matters because prices are set for a period of time with base on expectations about the environment in this period (see Ball 1995).

[6] Their main concern was the influence of inflation on the asymmetric effects of positive and negative monetary shocks.

[7] Depending on parameter values it is possible that a substantial amount of upward adjustments is also triggered. An instantaneous price increase or decrease may result. As we argue in section 4, there is no important output loss as a consequence of this effect.

a consequence of that, the distribution of price deviations changes abruptly, becoming nearly symmetric. Our results show that this effect practically annihilates inflation inertia.

If money demand increases with stabilization, without an accommodating increase in money supply, it is possible that there are output losses, but no inflation inertia. Nevertheless, the policymakers could achieve virtually costless disinflation by simply adjusting the level of money supply at the moment of stabilization. However, perfect credibility could be difficult to achieve in a situation where the government increases substantially the money supply.

Our results therefore imply that credibility is important for the success of monetary stabilizations even in the presence of price rigidity. However, in a given environment, high credibility may not be attainable. This may be due to past failures in stabilization plans, or to underlying fiscal imbalances. In other situations, it may be attainable but at a high cost. Policymakers may need to squeeze liquidity in order to gain or maintain credibility. In cases where policymakers have to live with low credibility, a fast disinflation could be achieved without substantial costs, provided that it is preceded by a mechanism of price alignment to eliminate distribution asymmetry.

We analyze some disinflation episodes to illustrate the policy implications above. We argue that the Real Plan in Brazil (1994) was an instance of a successful stabilization where credibility was low, and a mechanism of price alignment was implemented. We also argue that a freeze of prices and wages is not an adequate mechanism of alignment, since it freezes the asymmetric price deviation distribution inherited from the high inflation period. The Austral Plan (1985) in Argentina exemplifies the argument. In our setting, inflation inertia and disinflation costs are directly related to the asymmetry in the price deviation distribution. The US data on cross section distribution asymmetries of price changes constructed by Ball and Mankiw (1995) allow us to interpret two recent disinflation episodes (1974-1976 and 1979-1982) in terms of our model.

A previous article on the consequence of state-dependent pricing rules for disinflation costs is Tsiddon (1991). Since there were no idiosyncratic shocks in his model, his analysis is restricted to the instantaneous price change caused by the change of optimal one-sided Ss rule in a credible disinflation. Blanchard (1997) informally develops some of the arguments we make. However, his analysis of credible disinflation is analogous to that of Tsiddon (1991) by taking into account only the instantaneous effect of the change of rules.

We proceed as follows: section 2 presents the model, the optimal pricing rule of individual agents and aggregate equilibrium that arises from a situation of stable nominal aggregate demand growth and inflation. Section 3 introduces the policy change and discusses how the effective path of the inflation may differ from the path that would be obtained in a frictionless economy. Numerical simulations for the path of inflation are then carried out for the case of no credibility in the monetary policy, because of its relative simplicity. Section 4 considers the more complex effects of a fully credible disinflation. In section 5, we study the effects of intermediate levels of credibility. Agents believe that monetary policy has changed to the policy announced, but attribute a constant hazard that the old monetary policy will be resumed. Variation in the degree of credibility is considered through changes in the hazard parameter. In order to generate those results, conditions that determine optimal pricing rules when the frictionless optimal price process follows a diffusion process with a drift that follows a jump process are derived, and the rules numerically evaluated. In section 6 we do a general evaluation of our results, and their policy implications. We also present anecdotal evidence consistent with the state dependent model. Conclusions are presented in section 7.

2. The Model and the Inflationary Steady State

In this section, we characterize the inflationary environment that precedes the disinflation policy. State dependency of pricing rules allows us to summarize the relevant information about the economy in the distribution of the price deviations (from the frictionless optimal level)[8]. We find the distribution of price deviations correspondent to a certain inflation rate by aggregating optimal individual pricing rules, derived under the assumption that this inflation rate will last forever.

2.1. Optimal pricing rule in a stable environment

We assume that the optimal level of the individual relative price, in the absence of adjustment costs, is given by:

$$p_i^* - p = vy + e_i \tag{2.1}$$

where p_i^* is the individual frictionless optimal price, p is the average level of prices, y is aggregate demand and e_i is an idiosyncratic shock to the optimal price level (all variables are in log)[9].

Nominal aggregate demand is given by the quantity of money:

$$y + p = m \tag{2.2}$$

Substituting the quantity money equation into equation 2.1 yields[10]:

$$p_i^* = vm + (1 - v)p + e_i \tag{2.3}$$

We assume that v is equal to one. This evades strategic complementarities in prices, simplifying aggregation substantially[11]. Thus, the aggregate component is

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[8] See Dixit (1993) for an excellent exposition of the optimization problem and Bertola and Caballero (1990) for both the individual and the aggregation parts.

[9] Equation 2.1 states that the relative optimal price depends on aggregate demand and on shocks specific to the firm. It can be derived from utility maximization in an yeoman farmer economy, as in Ball and Romer (1989).

[10] This equation can also be derived directly from other specifications, such as Blanchard and Kiyotaki (1987), where real balances enter the utility function.

[11] The inclusion of strategic complementarities should magnify departures from the natural output level, but should not change the qualitative insights of the simpler model. Caplin and Leahy (1997) is one of the few articles to include price interdependence among agents in the state dependent literature. Their results are not qualitatively different from Caplin and Leahy (1991), where each individual optimal price depends only on the money supply.

reduced to the money supply:

$$p_i^* = m + e_i \tag{2.4}$$

To keep an individual price aligned to its optimal level is costly due to the existence of a lump-sum adjustment cost k. On the other hand to let the price drift away from the optimal entails profit losses, that flow at a rate $l(p_i - p_i^*)^2$ [12]. Without loss of generality we assume l to be equal one[13]. Time is discounted at a constant rate ρ.

Given the stochastic process for the optimal price, each price setter solves for the optimal pricing rule. We assume that e_i follows a driftless Brownian motion and that the money supply has a deterministic constant rate of growth π[14]. Thus, the frictionless optimal price is a Brownian motion with a drift given by the rate of the money supply growth:

$$dp_i^* = \pi dt + \sigma_i dw_i \tag{2.5}$$

where w_i is a Wiener process.

Given this, the optimal rule is characterized by three parameters $(L; c; U)$, where c is the target level for adjustments and, L and U are the levels of price deviation which trigger upward and downward adjustments, respectively[15].

Figure 1 plots the values of $(L; c; U)$ for different values of the inflation parameter, π, while the other parameters are fixed. The price setters take into consideration that the price will be depreciated soon with high probability and because of that reset their prices at a level higher than the optimal one. Thus, the optimal target point, c, is always greater than zero, and increases with inflation. The size of the upward adjustments, $c - L$, also grows with inflation in order to prevent a too high frequency of adjustments, which will result in a large increase in adjustment costs.

In what follows our main objective is to characterize the behavior of the aggregate price level, p, during disinflation. It will be useful to relate it to the money supply and to the average price deviation or disequilibrium, z:

$$p = \int p_i di = \int (p_i^* + z_i) di = \int (m + e_i + z_i) di = m + z \tag{2.6}$$

Substituting equation 2.6 into the money quantity equation results that the level of output is the symmetric of the average price deviation:

$$y = -z \tag{2.7}$$

2.2. The Inflationary Steady State

The inflation rate depends not only on the rate of growth of the money supply, but also on the distribution of price deviations. Given the change in each individual frictionless

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[12] Observe that this form corresponds to a second order Taylor approximation to the profit loss whenever the second derivative of the profit function is constant.

[13] The optimal rule depends only on k/l.

[14] In later sections we deal with alternative assumptions about m.

[15] See Dixit (1993) for a derivation of the optimal rule.

optimal price, the distribution of price deviations will govern the proportion of units with positive and negative price adjustments, and will determine the new distribution of price deviations. When the distribution of price deviations is the ergodic one, the average price deviation z is constant[16]. Thus, equation 2.7 implies that output is constant, and the inflation rate must be equal to the rate of growth of the money supply.

If a certain rate of money growth is kept constant indefinitely, the distribution of price deviations will converge to the ergodic one. Then, if the rate of change of the money supply is unaltered for a long period of time, it is reasonable to assume that the distribution of the price deviations is ergodic and that the price inflation is equal to the rate of money growth. We can say that the economy is in an inflationary steady state.

Each inflationary steady state will have an ergodic distribution of price deviations associated to it through a pricing rule, in the following way: given a volatility parameter for the idiosyncratic shocks, σ_i, each inflation rate π is associated to a different optimal pricing rule, that together with the stochastic process parameters for p_i^* jointly determine the ergodic distribution[17].

For an example, suppose that inflation has been equal to zero for some time. In this case, the optimal pricing rule of firms entails $L = -U$ and $c = 0$. The ergodic density of price deviations for this case is shown in Figure 2. It is symmetric around zero and decreases linearly with the absolute size of price deviation. The existence of adjustment costs will cause inaction at the microeconomic level, and therefore some firms will have prices that are different from the frictionless optimal. The frictionless optimal price of each firm is changing with time due to the existence of idiosyncratic shocks. Since we are assuming that there is a very large number of firms, the ergodicity of the distribution assures that it will be invariant to the occurrence of those shocks.

Figure 3 shows the ergodic density for the same volatility of idiosyncratic shocks, but for a high inflation rate. The shape of the density is extremely sensitive to the inflation rate. With a positive, high inflation, the fraction of firms that are close to the lower barrier L is much larger than the fraction of firms close to the upper barrier U. This comes from the fact that with a large, positive inflation the optimal price tends to appreciate, resulting in much more frequent upwards than downwards price adjustments. The ergodicity of the distribution again implies that microeconomic frictions have no effect on output. However, this is a long run phenomenon. If there is a structural change in the economy, as a new monetary policy, the microeconomic frictions might, in principle, matter, and output can be affected. In the next sections we will examine the transition dynamics between a high inflation and a zero inflation steady states using different credibility assumptions. For expositional clarity, we start with the no credibility case.

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[16] This is true only in the absence of aggregate uncertainty. Whenever aggregate shocks are present, the distribution of price deviations fluctuates through time and the ergodic distribution is only the time average of those distributions. See Bertola and Caballero (1990) for a derivation of the ergodic distribution and its properties.

[17] See Bertola and Caballero, 1990.

3. Disinflation with No Credibility

Suppose that the economy is initially in a high inflation steady state, as the one depicted in Figure 3. The money has been growing at a constant rate, and agents believe that this state will last forever. Then, the monetary authorities decide suddenly to stop printing money and to keep the money supply constant indefinitely. Assume, for simplicity, that the agents never believe in this change, and because of that maintain the same pricing rules they were following before. Notice that this does not mean that they will automatically continue to increase their prices: since the rules are state-dependent, any price increase must be triggered by a simultaneous increase in the frictionless optimal price. However, our simulations show that inflation will continue to grow for several months. What is the reason for that?

The substantial asymmetry of the distribution of price deviations associated to the inflationary steady state indicate that there is a large proportion of firms with prices far below their optimal one. Since their price deviations are close to the trigger level, a small positive idiosyncratic shock to the optimal price of each one of those firms may be enough to trigger a large price increase from them. Thus, large price increases may be numerous although there is no macroeconomic fundamentals driving them. On the other hand there are few firms with prices far above their optimal one. Therefore, price decreases will be much less numerous. With the continued incidence of idiosyncratic shocks, the asymmetry of the price deviation distribution is corroded, hence reducing residual inflation. Notice that inflation converges to zero, even though firms never believe the disinflation policy.

Figure 4 shows the path of inflation after the non-credible policy change starting at different steady state levels of inflation (see Bertola and Caballero (1990), for the discretization of the continuous time model in which the simulations are based). There is an instantaneous fall in the inflation rate[18]. Inflation is then gradually reduced, as the asymmetry of the initial price-deviation distribution decreases. A higher initial inflation results in a large inflation rate after money supply is halted. The role of idiosyncratic shocks and the timing of their effect are illustrated by the results depicted in Figure 5. A higher idiosyncratic uncertainty initially causes higher inflation inertia, because a larger proportion of price increases in triggered. However, the asymmetries in the price-deviation distributions are eroded faster in this case, ensuing a lower residual inflation after some time has elapsed[19][20].

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[18] Differentiating equation 2.6 , we get dpdt = dmdt + dzdt: Inflation jumps down since the first component jumps from À to zero. This is in contrast to time dependent models where inflation falls continually.

[19] The idiosyncratic uncertainty also affects the optimal rules, and by consequence the steady state distribution of price deviations. A higher uncertainty will increase the upper barrier and will decrease the lower barrier. This should reduce the overall asymmetry of the distribution, and thereby reduce inflation inertia. However, this effect should be small as compared to the direct effect mentioned in the text.

[20] The distribution of price deviations will converge in the long run to an ergodic distribution which is different from the one associated with a no inflation steady state. The distribution is linear, as in the steady state, but asymmetric, because the pricing rules are still associated with the old inflationary state. This result is mentioned as a curiosity, since a persistent state of no inflation, in which economic agents are certain that inflation will be high very soon, is not plausible.

It is important to notice that since money supply is constant after the monetary policy change, the rate of change in output is symmetrical to the inflation level. Thus a persistent inflation implies in output reductions, and contrary to the intuition based on time-dependent models[21], the higher the initial inflation, the larger is the output loss caused by disinflation and the longer the period of inflation inertia.

4. Disinflation with Perfect Credibility

Consider now that there has been constant inflation for some time, and that the monetary authorities credibly announce that money printing will be halted. The distribution of price deviations is initially asymmetric as in Figure 3. However, because the change of monetary policy is perfect credible, the agents will change instantaneously their pricing rules, resulting in a sudden change in the price deviation distribution, which will also cause an instantaneous price variation. The inflation inertia will hinge on the asymmetry of the new distribution.

In this section we examine the effects of a perfectly credible disinflation under two alternative money demand specifications: the quantitative equation 2.2 (subsection 1), as in the section above, and the Cagan specification (subsection 2). The former does not take into account explicitly the effect of inflation reduction. However one can interpret the variable m as the nominal aggregate demand, and assume that the Monetary Authorities set the trajectory of the money supply that corresponds to our path for nominal aggregate demand. Thus, under this interpretation, when the variable m is halted, money supply is increased by an amount just enough to satisfy the higher money demand due to lower inflation expectations and maintain the nominal aggregate demand constant. Alternatively, under the Cagan specification, when the variable m is halted, one should interpret that money supply will be kept constant, despite the increase in money demand caused by lower inflation expectations.

4.1. Quantitative equation

The new distribution will have an atom at the new target level, because of the large number of downward adjustments (and possibly upward adjustments too) instantaneously triggered. It is also substantially less asymmetric than the distribution inherited from the inflationary steady state. The main reason is that the reduction of the upper barrier eliminates the portion with lower density at the right side of the old distribution. Figure 6 depicts some price deviation distributions immediately after the credible policy announcement.

A more detailed view of the distribution change is necessary to understand the resulting instantaneous price variation. First observe that a high inflation entails a very large upper barrier. The reason is that agents with prices substantially superior to the frictionless optimal price will not decrease them, because they foresee a fast erosion

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[21] In time-dependent models one can imagine that a higher inflation causes a reduction of the periodicity of adjustments, which can reduce inflation inertia. While it is certain that disinflation will be faster, it is not guaranteed that disinflation costs will be absolutely lower, since if the periodicity is fixed, higher initial inflation rates imply in higher disinflation costs, as in Ball (1994).

of this gap. By contrast, when there is no trend in the frictionless optimal price, any difference between the actual price and the frictionless optimal level is expected to remain unaltered, and large price deviations are not tolerated. Therefore, the upper barrier reduces substantially with a credible fall in the money supply growth. This causes a downward adjustment of all prices who were at the interval between the old and the new upper barriers. The effect of inflation reduction on the lower barrier is small and ambiguous, as noticed by Blanchard (1997). If it decreases with inflation fall, the only instantaneous effect results from price decreases caused by the reduction of the upper barrier.[22] This is the case depicted in bold line (initial inflation 1.5 and the standard deviation is 0.3) in Figure 6. Then, we will have an instantaneous deflation. When it increases, its movement trigger price increases from the units with price deviation between the old and the new lower barrier. Despite the higher density of units at the lower part of the distribution, the net effect is ambiguous[23]. In Figure 6 we illustrate two cases where the upper barrier moves up. When initial inflation is 1.2 and standard deviation is 0.15 there will be an initial price level increase, as indicated in Table 2. When initial inflation is 1.5 and standard deviation is 0.1 there will be a initial price level decrease, although the movement of the lower barrier led some units to increase their prices.

Table 1 shows that no significant persistent output loss is generated by this instantaneous effect. If some important deviation from the natural output occurs, it will be an output gain, as in the first column of Table 1. For this reason we should concentrate on the dynamics that results from the interaction between idiosyncratic shocks and the price deviation distribution. For a given level of idiosyncratic uncertainty, the persistence of inflation hinges solely on the asymmetry of the new distribution of price deviations. As depicted in Figure 6, the new distribution will be substantially less asymmetric than the distribution inherited from the inflationary steady state. Thus, the abrupt change of rules induced by the credible change of monetary policy destroys the mechanism of inflation reproduction. Despite substantial price stickiness at the microeconomic level, inflation is eliminated nearly instantaneously, at most with very little output loss as illustrated by Tables 1 and 2 and Figure 7.

Figure 7 depicts the inflation inertia resulting from the simulation of a credible disinflation when the economy has been for a long time with an instantaneous inflation rate of 1.5 a year[24]. The parameter value for the standard deviation of the idiosyncratic shocks is 0.3. The initial optimal price rule is $(-0.25, 0.2, 0.45)$ and the initial distribution of price deviations is portrayed in Figure 3. When the money supply printing is credibly stopped, the price rule changes immediately to $(-0.27, 0, 0.27)$

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[22] As Blanchard (1997) points out, since the target level is reduced when inflation falls, and the inaction range between the lower barrier and the target level should also be reduced, the resulting effect on the lower barrier will depend on which reduction is greater. When inflation reduction is high as compared to the variance, the lower barrier should increase, as in the case of one-sided Ss policies (see Tsiddon, 1991). The combination of high initial money growth rates with much lower idiosyncratic uncertainty in the simulations reported below were chosen to produce cases where the lower trigger increases.

[23] The reason is that the magnitude of the upper barrier reduction may also be higher enough than the magnitude of the lower barrier increase to compensate for the difference in densities.

[24] This is equivalent to an annual inflation of 348%.

Table 1A

	Accumulated Output Gain		
	$\pi = 1.5; \sigma = 0.3$	$\pi = 1.2; \sigma=0.15$	$\pi = 1.5; \sigma=0.1$
Instantaneous*	0.000004	-0.000003	0.000002
1 day	0.001477	0.000034	0.000022
5 days	0.006665	0.000221	0.000116
10 days	0.011087	0.000485	0.000233
20 days	0.016783	0.001039	0.000465
30 days	0.020786	0.001598	0.000691
60 days	0.029675	0.003238	0.001345
120 days	0.043744	0.006301	0.002560

* measured as if the effect persisted for a whole day

Table 1B

	Inflation Rate		
Cases	$\pi = 1.5; \sigma = 0.3$	$\pi = 1.2; \sigma=0.15$	$\pi = 1.5; \sigma=0.1$
Instantaneous*	-0.520733	0.344202	-0.308986
1 day	-0.234020	-0.197199	-0.095832
5 days	0.054004	-0.002781	0.000131
10 days	0.026353	-0.000984	0.000214
20 days	0.008312	-0.000044	0.000228
30 days	0.003644	0.000112	0.000211
60 days	0.000747	0.000184	0.000165
120 days	0.000241	0.000115	0.000120

* measured as if the effect persisted for a whole day

and the distribution changes instantaneously to the base case depicted in Figure 6. All the units with price deviation between $0,27$ and 0.45 decreased their prices to the frictionless optimal level, generating an atom in the new distribution. This also caused an instantaneous deflation, as illustrated in Table 2. The distribution in Figure 6 is much more symmetric than the one in Figure 3. However there is a small empty space in the left side, because of the decrease of the lower barrier. In the first day subsequent to the policy change, there will be a small deflation: while the space on the left side of the distribution is not filled there will be no upwards price adjustments. According to Figure 7 and Table 2 after some time there will be a small inflation until convergence to zero inflation.[25] This inflation is negligible, specially if compared to the original level, which leads us to conclude that disinflation can be attained almost instantaneously without costs[26].

4.2. Cagan specification

In order to account for changes in money demand at the moment of stabilization, we assume the following functional form for the relationship between money demand, output and expected inflation:

$$m - p = y - a\pi^e; \quad a > 0 \tag{4.1}$$

This is the exact functional form used by Cagan (1956). As stabilization occurs, reducing expected inflation, money demand increases.

The only change in the model occurs at the moment of stabilization, as expected inflation drops to zero[27]. If we let $\pi > 0$ be the pre-stabilization rate of money growth, the effect of the instantaneous change in inflation expectations is equivalent to a negative shock to nominal aggregate demand of a size equal to the elasticity of money demand at the inflationary steady state: $\Delta(y + p) = -a\pi.$

Cagan (1956) estimated the parameter a using monthly data coming from different hyperinflation episodes[28]. The point estimates for the different hyperinflations ranged from 2.3 to 8.55. The point estimate from pooled data was 4.68[29]. Phylatkis and Taylor (1993) examined data on several Latin American countries during a high inflation period (the 1970 and 1980's)[30]. Their estimates vary from 7.39 to 16.87.

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[25] While inflation converges to zero, the distribution of price deviation converges to the triangular distribution of Figure 2, which is associated to the zero inflation steady state.

[26] Notice that the time unit in Figure 7 is one day, while in Figures 4 and 5 is one week.

[27] This is not exactly correct because actual inflation takes some time to converge to the rate of money growth even under perfect credibility. Since using the actual inflation rate post-stabilization as expected inflation would be too complicated, we use this approximation.

[28] Cagan defines hyperinflation as a situation in which the rate of inflation is above 50% a month. The actual episodes are: Austria (1921-22), Germany (1920-23), Greece (1943-44), Hungary (1922-24), Poland (1922-23) and Russia (1921-24).

[29] Although there may be econometric problems with Cagan's estimates (as pointed out by Sargent, 1977), Sargent's (1977) own estimates (for the same data) lie in roughly the same range as Cagan's. Furthermore, Goodfriend (1982) reexamines the same data using an alternate estimation method and finds results that are very similar to Cagan's.

[30] Average monthly inflation in these countries varies from 4.67% to 10.30% .

This seems to indicate that a range of $\hat{a}$ between 2 and 17 for monthly variables seems appropriately conservative, at least for economies characterized by high inflation[31].

The dynamics of inflation and output depends on the interaction between the price deviation distribution after the shock and idiosyncratic disturbances. The price deviation distribution has an asymmetry which is in the opposite direction of the one engendered by the inflationary steady state. The negative aggregate shock shifts the distribution to the right, leaving the region close the lower barrier empty. A substantial number of units adjusts downwards instantaneously, as they are displaced to the right of the upper barrier. Thus, the instantaneous effect is a sizeable fall in both price level and output. As time passes the idiosyncratic shocks causes more downward adjustments as they interact only with the upper part of the price deviation distribution. Hence, the recession is attenuated by the ensuing deflation, as accumulated output loss increases at decreasing rates.

If the Cagan elasticity or initial inflation are very high, which corresponds to a very large negative shock, practically all units adjust downwards instantaneously. The inherited distribution is composed solely of an atom in the zero position, which is of course symmetric. Therefore there is no ensuing effect on inflation and output.

Tables IIa and IIb show the simulation results for inflation and accumulated output loss. In these tables, we fix the standard deviation of idiosyncratic shocks at 0.3[32]: Table IIa shows the impact of the Cagan elasticity on the simulations, for an inflation parameter of 0.9[33]. It is clear that output losses can be very substantial. For an example, if the Cagan elasticity is 4.68 (as estimated by Cagan), the accumulated output loss after 120 days is 23.7%. Interestingly, if the elasticity is high enough ($a = 8$, for an example), output losses decrease, as explained above. However, if a is equal to 2, output losses are even starker, as shown in the table.

In table IIb we fix a at 4.68, and evaluate the effects of different initial inflation rates. Again, the effect of higher inflation is to increase the size of the initial negative demand shock. As initial inflation increases from 0.3 to 0.9 and 1.5 a year, output losses decrease.

5. Disinflation with Imperfect Credibility

The assumption of imperfect credibility is more realistic. The economic agents in general do not fully believe that a change in the monetary policy will last forever. It is not true, either, that they are absolutely sure that the new policy will be abandoned immediately. Here we model imperfect credibility as a conjecture that in each finite

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[31] In order to adjust for continuous time, and for the fact that our time unit is annual, we let:

$$a = \frac{\hat{a}[\exp(\pi)^{1/12} - 1]}{\pi}$$

where $\hat{a}$ is the value estimated using monthly data, and π is our inflation level before the stabilization. Observe that if $\hat{a}$ is a structural parameter, a is not.

[32] If standard deviation is higher, output losses become more substantial. The reason is that the inaction range $(U - L)$ increases. Therefore, less agents adjust prices downward at the moment of stabilization, and a greater part of the negative shock feeds into output losses.

[33] This is equivatent to an actual inflation rate of 145% a year.

Table 2a

Inflation Rate	0.90	0.90	0.90
Standard Deviation	0.30	0.30	0.30
Cagan Elasticity	2.00	4.68	8.00

Days	**Inflation**		
1	-25.918	-113.877	-224.136
5	-0.718	-0.617	0.000
10	-0.505	-0.392	0.000
20	-0.352	-0.219	0.000
30	-0.277	-0.144	0.000
60	-0.157	-0.063	0.000
120	-0.057	-0.021	0.000

Days	**Accumulated Output Gain**		
1	-0.014	-0.008	0.000
5	-0.066	-0.036	0.000
10	-0.124	-0.065	0.000
20	-0.222	-0.109	0.000
30	-0.302	-0.143	0.000
60	-0.475	-0.211	0.000
120	-0.640	-0.273	0.000

Table 2b

Inflation Rate	0.30	0.90	1.50
Standard Deviation	0.30	0.30	0.30
Cagan Elasticity	4.68	4.68	4.68

Days	**Inflation**		
1	-12.423	-113.877	-224.316
5	-0.603	-0.617	-224.316
10	-0.488	-0.392	0.000
20	-0.372	-0.219	0.000
30	-0.298	-0.144	0.000
60	-0.169	-0.063	0.000
120	-0.061	-0.021	0.000

Days	**Accumulated Output Gain**		
1	-0.014	-0.008	0.000
5	-0.068	-0.036	0.000
10	-0.129	-0.065	0.000
20	-0.234	-0.109	0.000
30	-0.322	-0.143	0.000
60	-0.508	-0.211	0.000
120	-0.685	-0.273	0.000

time interval there is a positive probability that the monetary authorities will renege. For simplicity, we assume that the probability of reneging at the next time interval is always the same. Thus, we model the rate of growth of the money supply after stabilization as a Poisson process with constant arrival rate λ. Once the new policy is abandoned, the agents believe that the old policy will be kept forever[34].

Specifically, after the stabilization policy is launched, the process for the money supply is:

$$dm = (0 + \pi 1_{\{N_t \geq 1\}})dt$$

where N is a Poisson counting process with constant arrival rate λ, and $1_{\{\cdot\}}$ is the indicator function. Then, the drift of the money supply will change from zero to π when an arrival occurs. We assume that stabilization is launched at time zero.

The parameter λ can be interpreted as a measure of credibility. The extreme cases of perfect and no credibility are associated with zero and infinity values for λ, respectively. Imperfect credibility is represented by positive finite values, and the higher is λ, the lower the degree of credibility.

In order to analyze disinflation effects under imperfect credibility, the first step is to derive the optimal pricing rule. Let us define T as the random time of the abandonment[35]. Then, after T, the monetary policy is the same as before, and the optimal pricing rule is exactly as in section 2. Before T, the money supply is constant, but there is a constant hazard λ that the old inflationary policy is resumed. So, the price setters have to take that into consideration when choosing their inaction range. We now turn our attention to the characterization of the optimal pricing rule under those conditions.

5.1. Optimal pricing rule under imperfectly credible monetary policy

First, we observe that the probability that the old monetary policy is resumed in the next interval $(t, t+s)$ is independent of t. Then, the optimal rule in the stabilization phase is time-invariant. Let us represent by G the value function after the monetary authorities renege. Then, the differential of the value function before stabilization is abandoned can be represented as:

$$dC(z_i) = \left[\frac{\sigma_i^2}{2}C''(z_i)dt + C'(z_i)\sigma_i dw_i\right] + dq[G(z_i) - C(z_i)] \tag{5.1}$$

where dq, the differential representation of the Poisson process, is one if the monetary authorities renege at this instant and zero otherwise. The first squared brackets expression is the usual formula for the differential of a function of a diffusion. If a Poisson arrival restores the old monetary policy, there will be an instantaneous

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[34] For simplicity, we specify a constant money supply growth rate after the stabilization flaw. To choose this inflation rate to be the same as the pre-stabilization level is appealing, if one believes that certain structural features of the economy determine the money supply growth.

[35] Formally:

$$T(\omega) = \inf\{t : N_t(\omega) \geq 1\}$$

jump in the value function, captured by the second term. The new value function G will correspond to the case of a steady inflation.

In the appendix, we derive the ODE for the value function C by using 5.1 in the continuous time Bellman equation, and solve for the optimal pricing rule.

5.2. Disinflation results

We carried out simulations for imperfectly credible disinflations., assuming that the money supply growth before the policy change and idiosyncratic uncertainty were both 0.3. After stabilization is launched, money supply growth falls to zero, and idiosyncratic uncertainty remains the same. Hence, the only source of aggregate uncertainty at this stage is the timing of the policy abandonment. We also supposed that firms believe that whenever the monetary authorities renege, money supply growth will return to its pre-stabilization value. In Figure 8 we show how the optimal trigger and resetting points (L, c, U) respond to different credibility parameters λ[36]. The two horizontal lines for each policy parameter show the values relative to the polar cases of perfect credibility and no credibility. The values for the policy parameters (L, c, U) increase continuously as λ gets higher, starting from the lower line representing the full credibility case, and growing towards the no credibility line. Recall that the parameter values for the no credibility case also correspond to the pricing policy before stabilization. Then, we see that if λ is high and credibility is low, the pricing rule will change very little. As argued in section 4, it is the change in the optimal pricing rule induced by stabilization that potentially reduces inflationary inertia. We should consequently expect inflationary inertia to be inversely related to credibility of the policy makers, as measured by the parameter λ.

Figure 9 shows disinflation paths for various credibility parameters. In the simulations performed, the monetary authorities never renege, although agents attribute a positive probability that it would occur in any time interval. Therefore inflation must converge to zero in the long run. Our aim is to evaluate how fast is this convergence, for different levels of credibility. In order to focus on the effects of credibility, we fix the remaining parameters of the model ($\pi = 0.3$, $\sigma_i = 0.3$, $\rho = 0.025$, and $k = 0.01$). The simulation results are as expected: inflation inertia increases as the level of credibility is reduced. When $\lambda = 10$, which means that the agents assign a probability of 8.2% that the stabilization will last at least one quarter, the inflation path closely resembles that of the no credibility case.

6. Evidence and Implications

6.1. Evaluation of results

When disinflation is credible the simulation results show that there is no inflation inertia. There is practically no output loss with the quantitative specification for money demand, while output loss could be substantial with the Cagan specification.

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[36] For easiness of interpretation observe that the probability that the old policy is not resumed before t is $e^{-\lambda t}$. So, if $\lambda = 0.3$, the probability that the stabilization policy is kept for at least one year is approximately 0.74.

The latter specification is more realistic, but as we argued above the quantitative equation experiment could be reinterpreted as situation in which the money demand behaves according to the Cagan specification and the government monetizes in order to compensate for the inflation expectation effect. Hence, if there is perfect credibility the government could disinflate instantaneously without cost if it increases money supply immediately after the stabilization announcement.

However, if perfect credibility is not a very realistic assumption, it becomes even less plausible in a situation where the government increases substantially the money supply. For credibility reasons, it should not be surprising to find disinflations where constant money supply causes a liquidity squeeze.

On the other hand, when credibility is imperfect, there are both output losses and inflation inertia. Both effects hinge on the asymmetry of the price deviation distribution.

Summarizing the discussion above there are two types of costly disinflations. The first one is associated with high credibility and little inflation inertia. The price deviation distribution is symmetric at the beginning of the disinflation. In the other one there is low credibility and inflation inertia. The asymmetric distribution of price deviations is the driving force behind those effects.

Our modelling strategy was to neglect the effect of aggregate shocks. The reason is that we were concerned mainly with average effects and the existence of aggregate shocks would complicate the model without modifying the average results[37]. However, in specific situations the price deviation distribution may differ substantially from the average (ergodic) one due to the incidence of aggregate shocks. The actual effect of monetary disinflation depends crucially on the initial price deviation distribution. A large aggregate shock or a sequence of small aggregate shocks could attenuate or enhance the asymmetry which is usually present in inflationary environments. For an example, a shock that increases the price of oil should increase the asymmetry of the price deviation distribution, making disinflation slower and costlier. Hence the effect of a monetary disinflation with a given degree of credibility may differ depending on the initial price deviation distribution.

In order to solve the model we had to assume away strategic complementarities in price setting. Specifically, we assumed that the frictionless optimal individual price does not depend directly on the aggregate price level. As illustrated by Ball (1994) and Caplin and Leahy (1997), the higher the degree of strategic complementarity, the more important are the real effects of monetary contractions. Thus one should expect that the introduction of complementarities in our model should magnify inflation inertia and the output costs of disinflation.

6.2. Policy implications

Our results imply that credibility is important for the success of monetary stabilizations even in the presence of price rigidity. Thus, the underlying policy and institu-

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[37] This is a straightforward consequence of the ergodic principle (Caballero and Engel, 1992). The effect of a monetary disinflation when aggregate shocks are present are shown in an earlier version of the paper (Almeida and Bonomo, 1996).

tional environment should be important, such as the degree of independence of the Central Bank and the fiscal regime.

However, in a given environment, high credibility may not be attainable. In other situations, it may be attainable but at a high cost. Policymakers may need to squeeze liquidity in order to maintain credibility.

In such cases our model implies that a fast disinflation could be achieved without substantial costs provided that it is preceded by a mechanism of price alignment to eliminate distribution asymmetry.

It is important to stress that a freeze of price and wages[38] is not an effective policy in this context. Such a policy freezes the distribution of relative prices of the day of the stabilization plan, with all the skewness caused by past inflation. As time elapses sectoral shocks interacts with the distribution asymmetry to increase the pressure to realign prices.

6.3. Some anecdotal evidence

There is considerable evidence that our framework is an useful benchmark for the analysis of actual disinflation episodes. We substantiate this claim with evidence on the features of the inflationary environment and on specific disinflation episodes.

6.3.1. Inflation and asymmetry in the distribution of relative prices

Lach and Tsiddon (1993) use disaggregated price data for 26 Israeli foodstuffs, and analyze the cross-sectional distribution of real prices for two periods. For a period of low inflation[39] (1978-1979), the hypothesis of symmetry cannot be rejected by the data. However, for the period of high inflation (1982)[40], the data reject the hypothesis of symmetry in favor of the alternative of skewness to the left (meaning that the upper tail of the distribution is thinner than the lower tail). The authors also consider the distribution of durations of price quotations. They conclude that the duration data are consistent with the predictions from two-sided menu cost models.

Ball and Mankiw (1995) use disaggregated, annual PPI data, for the US economy, in the period of 1949 to 1989. They analyze the distribution of relative price changes, and test the hypothesis that the skewness in this distribution is related to the level of inflation. Their results are also consistent with models based on menu costs. Years of high inflation tend to be years of substantial positive skewness in the distribution of relative price changes. The relationship between inflation and skewness is statistically significant, and are robust across different measures of asymmetries in the distribution of price changes[41][42].

The evidence on Ball and Mankiw (1995) is not based on the asymmetry of the distribution of price deviations. However, it is easy to show that a negatively skewed

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[38] Such as in the Argentinian Austral plan (1995), or in the Brazilian Cruzado plan (1996).

[39] 3.9% monthly inflation.

[40] An average of 7.3% a month.

[41] Vining and Elwertowski (1976) is an earlier study for the American economy. Their findings are similar to Ball and Mankiw's.

[42] Mizon, Safford and Thomas (1989) and Blejer (1983) have similar evidence for the UK and Argentina respectively.

price deviation distribution is directly related to a positively skewed price change distribution. Therefore their evidence is supportive of our framework.

6.3.2. Specific disinflation episodes

One of the novel predictions of our framework is that, not only does inflation cause asymmetries, but these asymmetries are a potential cause of residual inflation after an stabilization plan.

The Argentinian Austral Plan (1985) Consider, for an example, the case of the Austral Plan in Argentina[43], in the period 1985-1987. The Austral plan was a hetherodox stabilization plan, which included actions in both aggregate demand, and direct control of prices and wages. According to Machinea and Fanelli (1988)[44], the Argentinian government recognized the importance of a realignment in relative prices, for the success of the stabilization plan. Before the plan was actually launched (in June, 1985), steps were taken in this direction, such as a flexibilization of controls on industrial prices, and an increase in beef prices, since the price of foodstuffs were lagging behind average historical levels. However, the authors acknowledge that adjustments in relative prices after the program was launched was an important factor contributing to the comeback of inflation. Inflation (measured by consumer prices) decreased from 30.5% a month in June, to 1.9% a month in October, but increased back to 4.6% in March of 1986.

It is not surprising that the attempt to realign relative prices before the stabilization plan was unsuccessful. According to our model, in an environment of high inflation (such as the Argentinian economy in the period preceding the Austral Plan, where inflation reached 25% to 30% a month), we should expect the distribution of relative prices to be skewed. The freeze of an important fraction of prices and wages in the economy could explain the initial success of the plan, even under imperfect credibility and relative price misalignment. As the pressure to realign prices increases (even in an environment of low overall inflation, such as the Argentinian economy immediately after the Austral Plan), inflation tends to fight back.

The Brazilian Real Plan (1994) A successful stabilization attempt based on a generalized mechanism of price realignment was the Brazilian Real Plan (1994)[45]. In March 1994, the government introduced an inflation index (URV) to serve as an optional unit of account for prices and contracts. As the index had stable real value, it was an attractive unit of account. The economy adhered massively to the new unit of account. On July 1st the old money was extinguished and the URV became the new currency (the "real"). In that moment monetary policy also changed, so that

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[43] The Brazilian Cruzado Plan was an experience in several aspects similar to the Austral Plan (see for example Modiano (1990)). The main ingredient was a freeze in prices. There was also mechanism to realign the wages (to the average of the last six months), but not the prices. The plan failed not only due to inflationary pressure caused by the lag of an important fraction of prices, but also due to generalized excess demand.

[44] See also Canavese and Di Tella (1988).

[45] For more details, see Bonomo (1997) and Franco (1996).

it became compatible with stabilization. The inflation rate fell abruptly from 45% a month in June to 6% a month in July, continuing to decrease afterwards. This result was specially striking, given the low degree of credibility. This was due both to the failure of several previous stabilization attempts and to structural fiscal imbalances.

Since the conversion to URV was voluntary, the firm would choose a relative price close to the its past average. This contributed to eliminate the underlying asymmetry in the distribution of price deviation. Then, when the new currency was launched there was no inflationary pressure due to inherited asymmetry. In such a scenario it is not surprising that disinflation was fast and costless even without credibility.

Recent Disinflation Episodes in the US (1974-1976 and 1979-1982) For the US economy, there is additional evidence on the relationship between asymmetries in the distribution of relative prices, inflation inertia and disinflation costs. Ball and Mankiw (1995) present data on the asymmetry of relative price changes, that we can relate to recent disinflation episodes.

The year of 1975 is identified by Romer and Romer (1989) as a year of disinflation, caused by a shift in monetary policy in April of 1974. The shift was a delayed response to the increase in inflation, that had been due to the OPEC-induced increase in oil prices. Disinflation was very slow initially, falling about 1% in the first year, while unemployment increased to 8.5%. The years of 1974 and 1975 were years of positive and declining asymmetry. In terms of our model this corresponds to a negative asymmetry in price deviation. A negative supply shock, as the oil shock, should have contributed to increase this asymmetry. Its persistence in the first few years of disinflation policy indicates that the policy had low credibility. Therefore the slow disinflation and high unemployment are consistent with our model. The subsequent fall in inflation from 1975 to 1976 is also consistent with the reduction in asymmetry in the same period.

Another experience of initially slow and costly disinflation is the period of the Volcker disinflation. Romer and Romer identify the moment of shift in policy as October of 1979. Inflation did not start to fall substantially until 1982. The initial period was also characterized by an increase in unemployment, up to 11% in 1982. The coefficient of asymmetry was initially positive and fell to virtually zero in 1982. In terms of our model, this initial asymmetry indicates that the policy had initially low credibility. The fast disinflation phase (after 1982) with no asymmetry is consistent with the interpretation that credibility reached a high level by 1982.

7. Conclusion

We used a state-dependent model where pricing rules were optimal to examine the costs of a money based disinflation under various assumptions about the credibility of the policy change. Our analysis allowed us to relate actual credibility and future inflation inertia to the asymmetry of the price deviation distribution. Thus, it provides an empirical framework for the investigation of disinflation experiences. Although we investigate some specific episodes, future empirical research should test the predictions of our model in a more systematic way.

An important implication of the state-dependent setting is that disinflation could be attained without substantial cost even in a situation of low credibility, provided that a mechanism of price alignment eliminates the asymmetry of the price deviation distribution. Thus, our model furnishes a criterium to evaluate policies that aim to affect price setting. Policies that do not eliminate the price deviation asymmetry inherited from the inflationary environment should not be effective. Thus, price freezing is not an effective anti-inflationary policy. We analyzed actual experiences of heterodox stabilizations where the facts are in accordance with our criterion.

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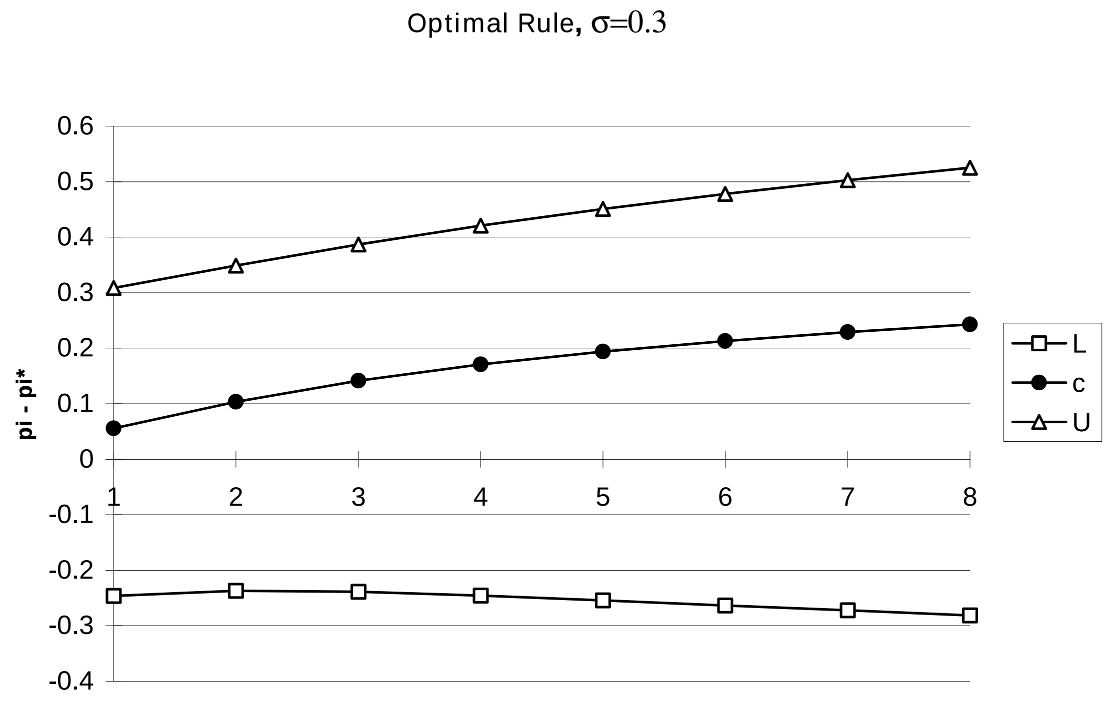

Figure 1

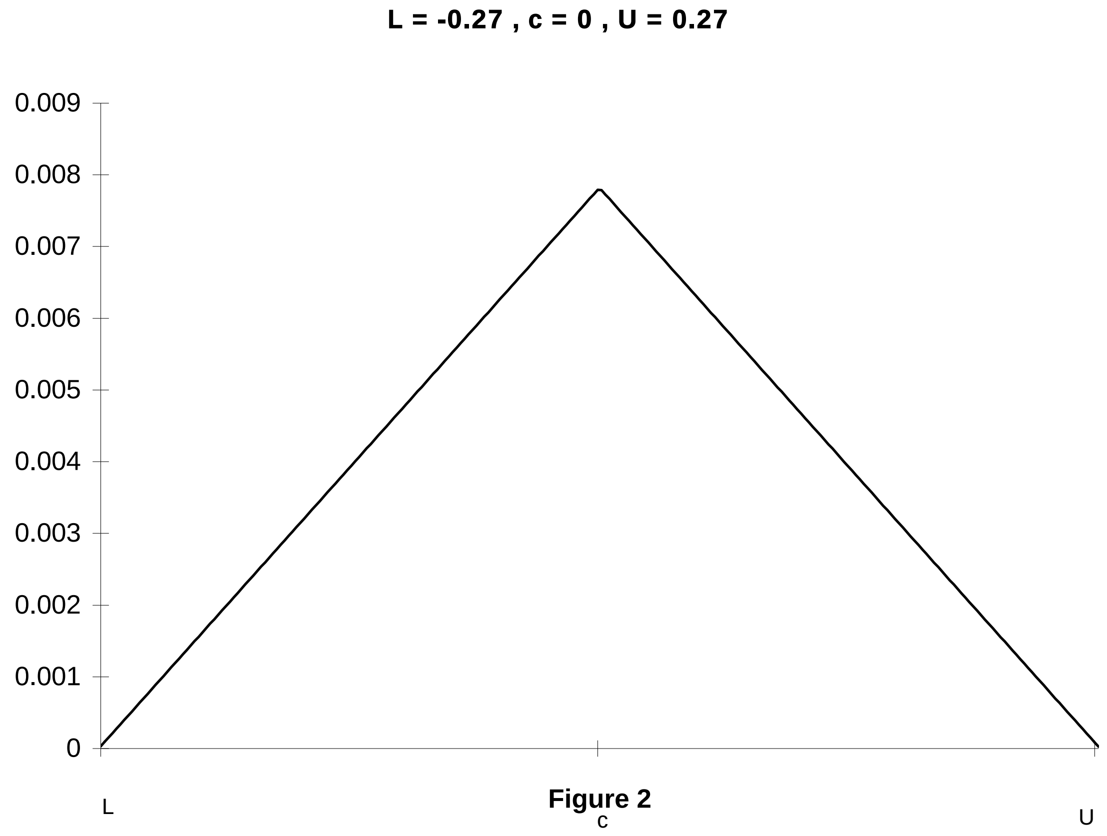

Figure 2

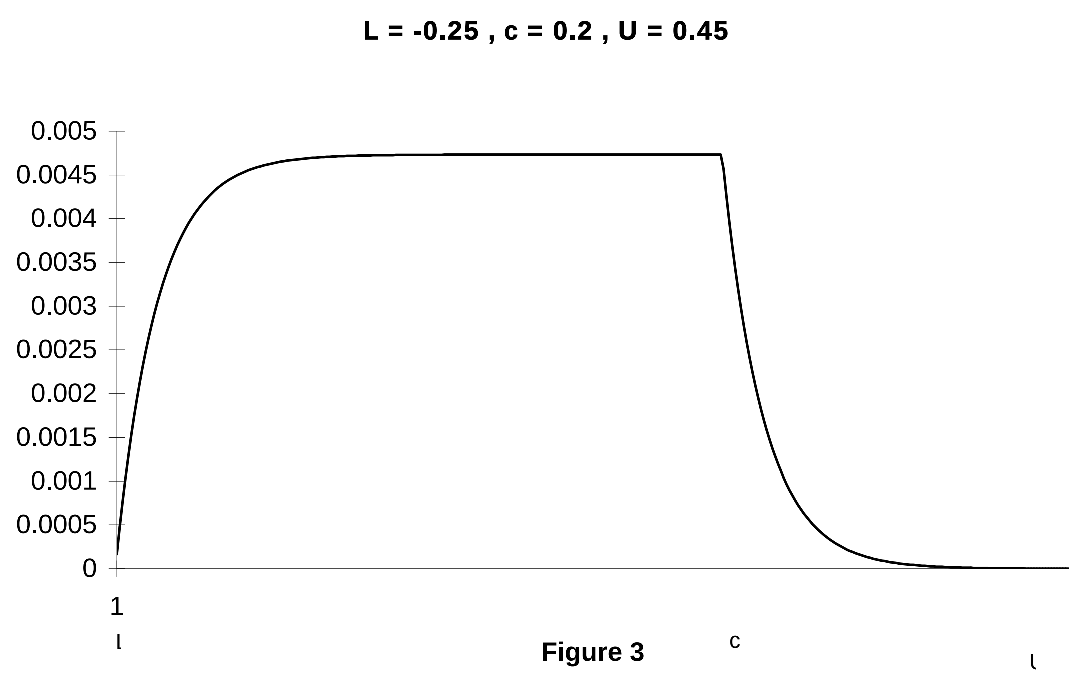

Figure 3

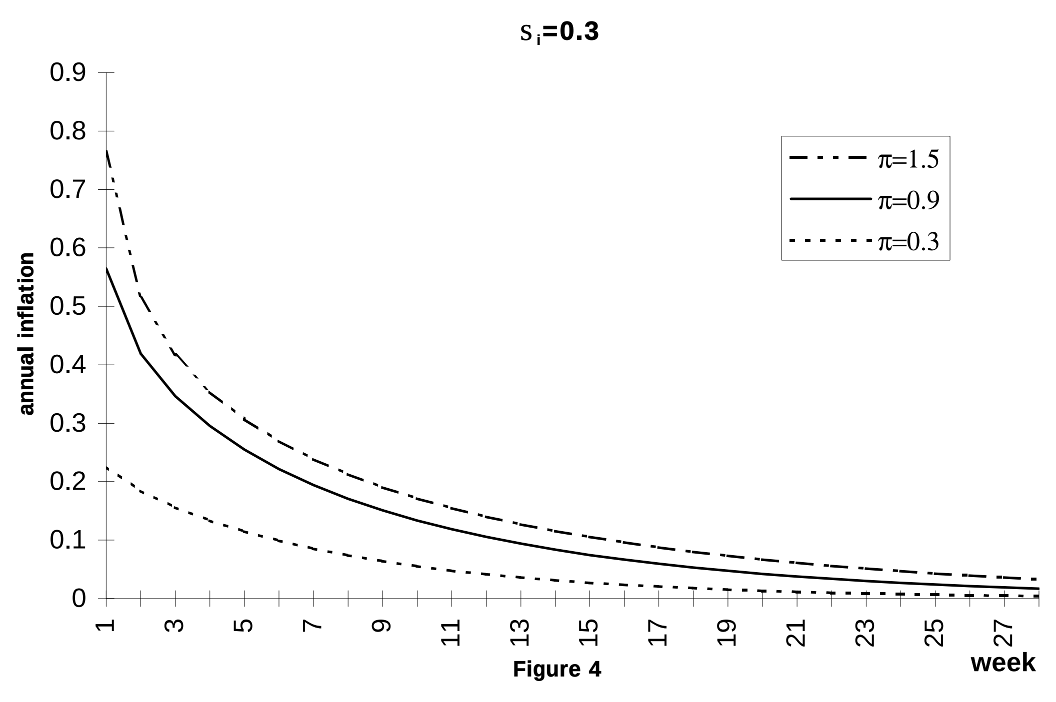

Figure 4

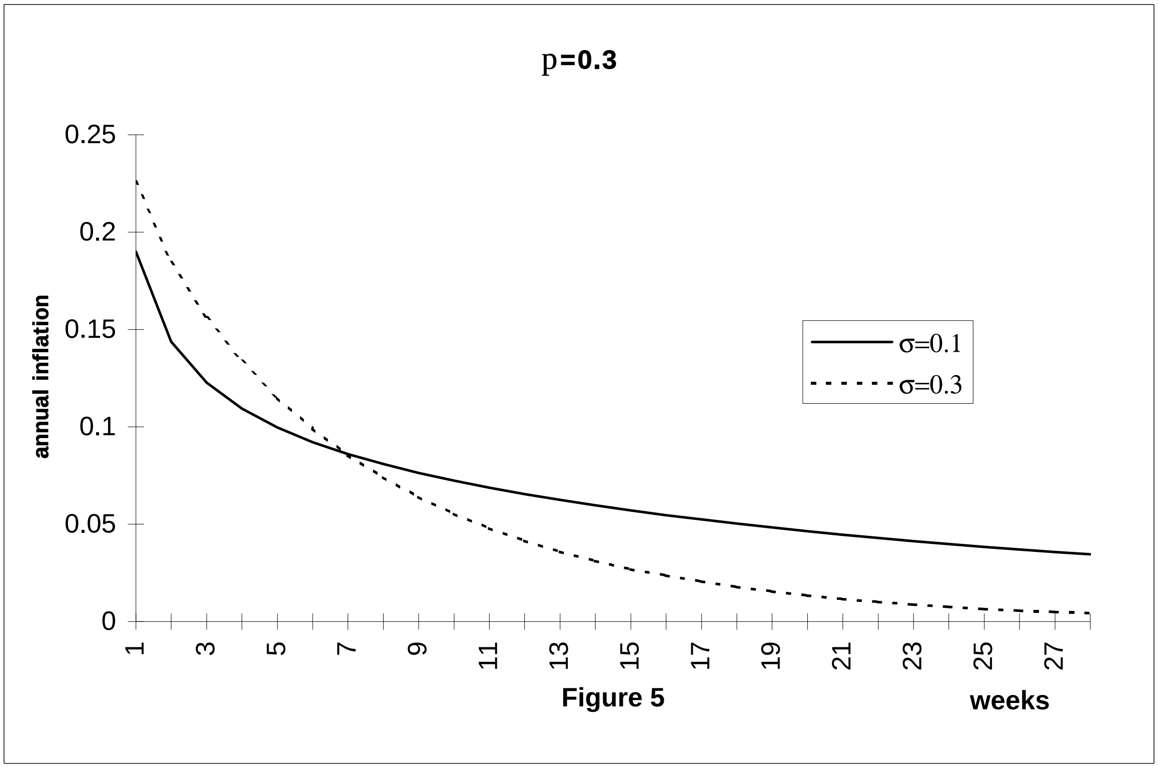

Figure 5

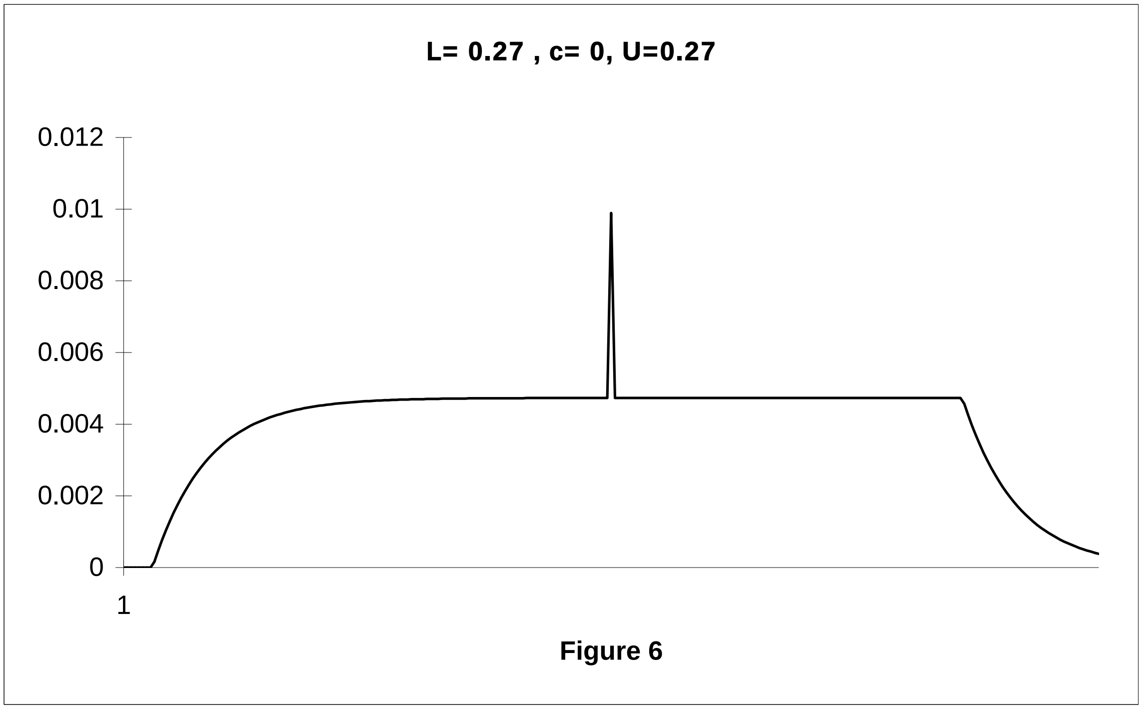

Figure 6

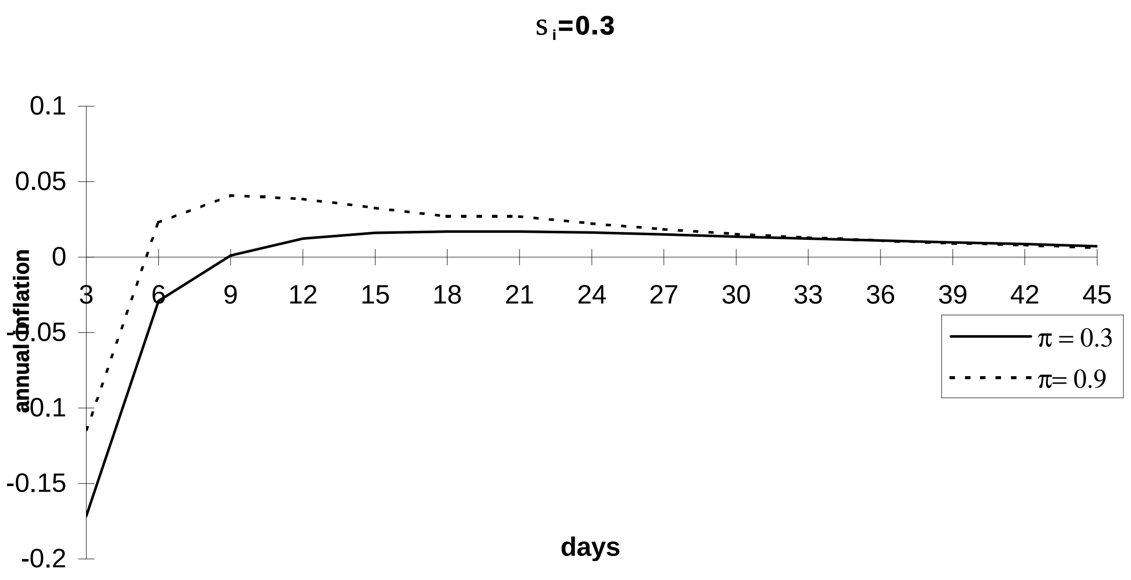

Figure 7

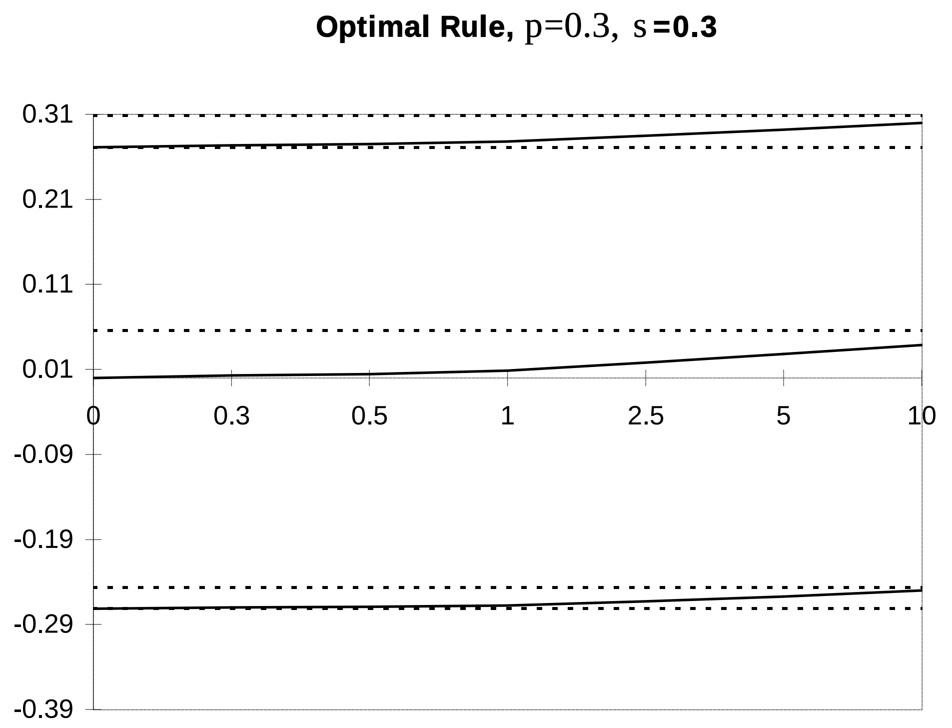

Figure 8

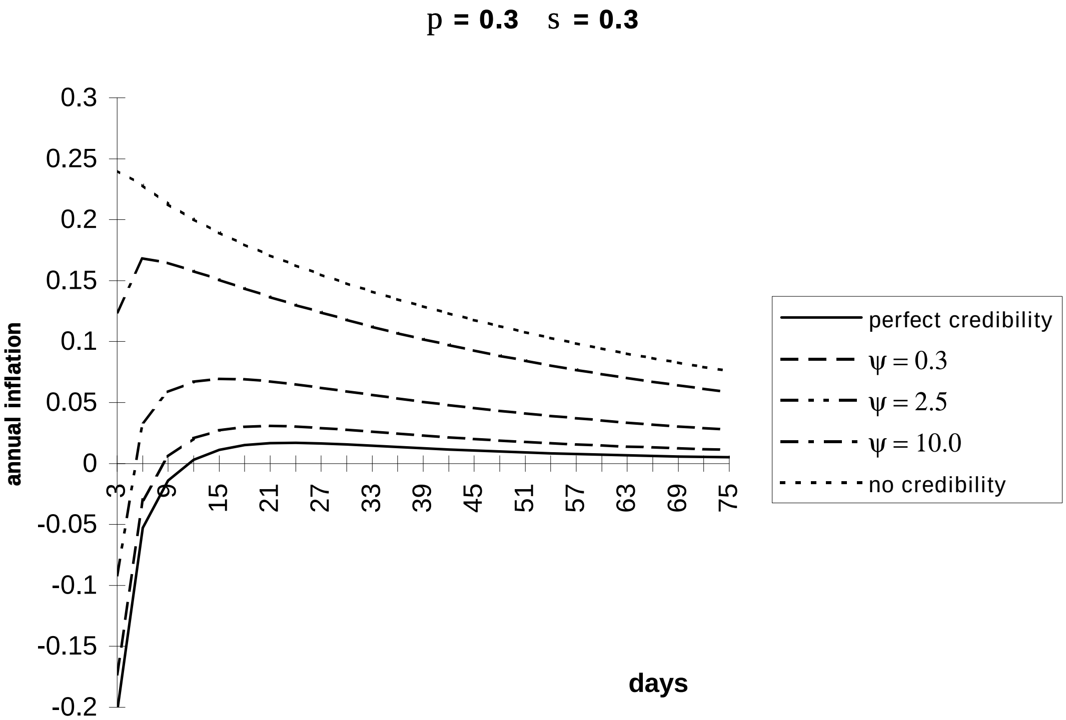
p = 0.3 s = 0.3
annual inflation
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
3
9
15
21
27
33
39
45
51
57
63
69
75
days
perfect credibility
ψ = 0.3
ψ = 2.5
ψ = 10.0
no credibility

Figure 9

APPENDIX

A. Optimal Pricing Rule under Imperfect Credibility

The value function C should satisfy the following equation, whenever the price deviation z is inside the region where it is optimal not to adjust :

$$\rho C(z_i)dt = z_i^2 dt + E_t[dC] \tag{A.1}$$

where the differential dC is given by equation 5.1 (in the text).

Taking expectations of equation 5.1 conditioned on the information at time t, we get:

$$E_t[dC(z_i)] = \frac{\sigma_i^2}{2}C''(z_i)dt + \lambda dt[G(z_i) - C(z_i)] \tag{A.2}$$

Substituting back into the Bellman equation (equation A.1), yields the following ordinary differential equation:

$$\frac{\sigma_i^2}{2}C''(x) - (\lambda + \rho)C(x) - x^2 + \lambda G(x) = 0 \tag{A.3}$$

The homogeneous solution is:

$$C_h(x) = Ce^{\gamma x} + De^{-\gamma x} \tag{A.4}$$

where

$$\gamma = \frac{\sqrt{2(\lambda + \rho)}}{\sigma_i}$$

We need a particular solution for A.3 in order to find the expression for the general solution. Once the latter is found, the constants C and D are jointly determined with the policy parameters $(L; c; U)$ by the Value Matching and Smooth Pasting Conditions We appeal to intuition in guessing that the following function is a particular solution of A.3.

$$C_p(x_0) = \int_0^\infty \lambda e^{-\lambda T}\left\{\int_0^T e^{-\rho s}E[x_s^2 \mid x_0; T]ds + e^{-\rho T}E[G(x_T) \mid x_0; T]\right\} dT \tag{A.5}$$

where x follows the stochastic process of z when there is no control, that is a driftless Brownian motion with diffusion parameter σ_i. The first term of the expression between curly brackets can be interpreted as the expected discounted flow cost of being away from the optimal from zero to T, while the second term is the discounted expected value when abandonment occurs. So, it is assumed that no control is exerted until T, when abandonment occurs, and that an optimal control policy is exerted from then on. Since the time of abandonment is stochastic, the expression between curly brackets is evaluated for each possible T and the result is weighted according to its density. Here, $\lambda e^{-\lambda T}$ is the probability density that the first jump occurs exactly at time T. The function G is the value function after abandonment, and its expression is given by equation ?? (with the constants and the policy parameters jointly determined by the VMC and SPC conditions for the rule after abandonment). Then, the conditional expectation of the value after abandonment, taken at time zero, is given by:

$$\begin{aligned} E[G(x_T) \mid x_0;T] &= E[E[G(x_T) \mid x_0;x_T;T] \mid x_0;T] \\ &= E\left[Ae^{\alpha x_T} + Be^{\beta x_T} + \frac{x_T^2}{\rho} - \frac{2\pi x_T}{\rho^2} + \frac{\sigma_-^2}{\rho^2} + 2\frac{\pi^2}{\rho^3} \mid x_0;T \right] \qquad \text{(A.6)} \\ &= Ae^{\alpha x_0 + \alpha^2 \frac{\sigma_-^2}{2} T} + Be^{\beta x_0 + \beta^2 \frac{\sigma_-^2}{2} T} + \frac{x_0^2}{\rho} + \frac{\sigma_-^2 T}{\rho} - \frac{2\pi x_0}{\rho^2} + \frac{\sigma_-^2}{\rho^2} + 2\frac{\pi^2}{\rho^3} \end{aligned}$$

where the first equality results from the law of iterated expectations, the second from the substitution of the value function when there is no uncertainty about the monetary policy, and the last one from taking expectations over x_T conditioned on x_0 and T.

By substituting the expression found in A.6 into ?? and integrating the resulting expression we obtain the final expression for the particular solution of A.3:

$$\begin{aligned} C_p(z) &= \frac{\lambda Ae^{\alpha z}}{\lambda + \rho - \alpha^2 \frac{\sigma_-^2}{2}} + \frac{\lambda Be^{\beta z}}{\lambda + \rho - \beta^2 \frac{\sigma_-^2}{2}} + \frac{z^2}{\rho} \\ &\quad - \frac{2\lambda \pi z}{(\lambda + \rho)\rho^2} + \frac{\sigma_-^2}{\rho^2} + \frac{2\lambda \pi^2}{(\lambda + \rho)\rho^3} \qquad \text{(A.7)} \end{aligned}$$

It is straightforward to verify that this particular solution satisfies A.3. Observe also that the limits of this particular solution actually make sense:

$$\begin{aligned} \lim_{\lambda \to 0} C_p(z) &= \frac{z^2}{\rho} + \frac{\sigma_-^2}{\rho^2} \\ \lim_{\lambda \to \infty} C_p(z) &= G(z) \end{aligned}$$

When $\lambda = 0$, the zero inflation policy is totally credible because agents believe that it is going to last forever with probability one. Hence, our particular solution should entail the expected present value of the cost of being away from the optimal when there is no drift and no control. When $\lambda \to \infty$; the new policy is not credible, and agents believe that the old inflationary policy will be resumed immediately. Consequently, the proposed particular solution should be equal to the value function in the inflationary environment when optimal control is exerted.

Finally, the value function is found by adding the particular solution to the solution of the homogenous differential equation:

$$\begin{aligned} C(z) &= Ce^{\gamma x} + De^{-\gamma x} + \frac{\lambda Ae^{\alpha z}}{\lambda + \rho - \alpha^2 \frac{\sigma_-^2}{2}} + \frac{\lambda Be^{\beta z}}{\lambda + \rho - \beta^2 \frac{\sigma_-^2}{2}} \\ &\quad + \frac{z^2}{\rho} - \frac{2\lambda \pi z}{(\lambda + \rho)\rho^2} + \frac{\sigma_-^2}{\rho^2} + \frac{2\lambda \pi^2}{(\lambda + \rho)\rho^3} \qquad \text{(A.8)} \end{aligned}$$

The constants A,B,® and ¯ are known from the solution for the value function G; for an optimal rule under perfect credibility (see Dixit, 1993). So, the only unknown parameters in this equation are the constants C and D. Those are determined jointly with the policy parameters $(L; c; U)$ using the equations A.9 and A.10 below :

$$\begin{aligned} C(L) &= C(c) + k \\ C(U) &= C(c) + k \end{aligned} \tag{A.9}$$

$$C^0(L) = C^0(U) = C^0(c) = 0 \tag{A.10}$$