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Inflation Targeting and Output Stability

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Abstract

This paper reexamines the effects of inflation targeting on output stability. It considers an economy with staggered price setting that is exposed to price shocks and where the policymaker cannot observe the current realizations of aggregate output and inflation. The paper shows that, if some price shocks can be anticipated, the effects of inflation targeting depend critically on the inflation indicator being targeted. Specifically, targeting headline inflation can severely destabilize output, while targeting inflation indicator of sticky prices may eliminate that problem and make the response of the output gap to aggregate shocks short-lived.

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I. Introduction

The adoption of monetary policy frameworks designed to maintain inflation broadly in line with an inflation target has become increasingly popular.[2] The proposal to use inflation targeting as the fundamental criterion for day-to-day monetary policy, however, remains controversial. The primary criticism of explicitly or implicitly adopting a monetary policy rule based on inflation targeting is that doing so would give no weight to other legitimate monetary policy goals, and that in consequence, it can lead to undesirable outcomes. This concern has been mainly directed at the possibility that inflation targeting generates excessive output instability.[3]

The conventional view in the academic literature indeed has been that, when prices are sticky, inflation targeting prevents the stabilization of output around its natural level. According to this view, such difficulty would not arise when the economy is hit by demand shocks, since in that case a monetary policy that tries to offset the effect of those shocks on demand helps to stabilize both output and inflation. In the case of supply shocks, however, the usual presumption is that targeting inflation destabilizes the output gap, since countering the effects of those shocks on prices through monetary policy generally induces an opposite variation in demand and output. The view that there is a conflict between inflation and output stabilization is often represented with the proposition that there exists a monetary policy tradeoff between the variability of inflation and the variability of the output gap.[4]

Recent results obtained using contemporary models of staggered price setting have challenged the conventional view, suggesting that inflation targeting may be conducive to output stability. King and Wolman (1996, 1998) and Goodfriend and King (1997) showed that, in economies where prices are set by monopolistically competitive firms according to a staggered price setting rule *à la* Calvo (1983) or *à la* Taylor (1979, 1980), inflation targeting can fully eliminate output gaps when the economy is exposed to monetary and productivity shocks—the latter being a type of supply shock. A similar result is implied by Rotemberg and Woodford's (1998) analysis of an economy with staggered price setting *à la* Calvo (1983) and that allows for shocks to monetary policy, spending, and natural output. King and Wolman (1996, 1998) and Goodfriend and King (1997) used their results to argue that the monetary authority should target inflation.

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[2]See Bernanke, Laubach, Mishkin, and Posen (1999) and the references therein.

[3]On the criticisms of a monetary policy rule based on inflation targeting see, for instance, Friedman and Kuttner (1996), McCallum (1996, 1997a), Summers (1996), Bernanke and Mishkin (1997), Bernanke and Woodford (1997), Cecchetti (1997), and Svensson (1996).

[4]The conventional view can be found, for instance, in Taylor (1980), Friedman and Kuttner (1996), Blanchard (1997), Fuhrer (1997), Erceg, Henderson and Levin (1998), and Rudebusch and Svensson (1998).

The robustness of these recent results, however, has been questioned. Implicitly, the main concern has been that the models on which these results are based assume that there are no discrepancies between headline inflation and inflation of the sticky prices in the economy (Blanchard, 1997, and Erceg, Henderson, and Levin, 1998), or what is the same under the terminology used in this paper, that the economy never is exposed to price shocks.[5] The models underlying these results also have been questioned because they assume that the policymaker can observe the value of current aggregate output and inflation when setting the value of its policy instrument (McCallum, 1993, 1997b). This paper studies the consequences of relaxing these assumptions, examining the effects of inflation targeting in an economy with staggered price setting that is exposed to price shocks, and where the policymaker cannot observe the current realizations of aggregate output and inflation.

The analysis below shows that, if some price shocks can be anticipated, the effects of inflation targeting on output stability depend critically on the inflation indicator being targeted. On the one hand, targeting headline inflation can severely destabilize the output gap. The reason is that targeting this type of indicator implies a monetary policy that must try to offset the effect of anticipated price shocks on headline inflation with changes in the opposite direction in the sticky prices of the economy, and thus on the expected and actual output gap. In the simple model examined below, such a monetary policy may be even incompatible with a stationary solution for the output gap. On the other hand, an inflation indicator of sticky prices may not only eliminate that problem but also make the response of the output gap to aggregate shocks short-lived. This requires that the inflation indicator being targeted focuses on the prices of the goods with sticky prices that directly depend on the expected output gap, excluding, for instance, the prices of the goods that are in fixed supply and the prices of imported goods. By removing the need to offset the effect on headline inflation of anticipated price shocks, targeting such an indicator can make inflation targeting consistent with a monetary policy aimed at eliminating expected output gaps, which, in turn, can greatly reduce the persistence of the movements in the output gap in response to aggregate shocks.

The remainder of this paper is organized as follows. The next section presents the basic model used for the analysis under the assumption that there are no price shocks, showing that under such assumption inflation targeting makes the effects of aggregate shocks short-lived. Section III allows for discrepancies between headline inflation and the relevant sticky-prices inflation indicator in the simplest possible way. Section IV examine the effects of inflation targeting using the monetary base instead of the interest rate as policy instrument. Section V provides concluding remarks.

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[5]King and Wolman (1996, 1998) and Goodfriend and King (1997) acknowledged that their results would not hold when the economy is exposed to price shocks such as one caused by a restriction in the supply of oil. However, they conjectured that the result of no conflict between inflation and output stabilization would be restored by defining the inflation target in terms of an index of sticky prices. This hypothesis is formally examined below.

II. Inflation Targeting in the Absence of Price Shocks

A. An Economy with Sticky Prices

We start by considering an economy in which headline inflation and the aggregate rate of change of the sticky prices of the economy are the same. The aggregate decisions of consumers and producers in this economy can be summarized with two behavioral equations. While these can be derived from explicit maximization of the objective functions of representative agents, we write them directly and explain them briefly, so that we can rapidly jump into the issues of most interest for this paper.

The first equation describes the aggregate rate of change of the sticky prices:

$$\hat{p}_t = \frac{1}{2}(1-L^2)\, E_{t-1}\left[\frac{P_t + P_{t+1} + \gamma\,(Y_t - Y_t^* + Y_{t+1} - Y_{t+1}^*)}{2}\right], \qquad (1a)$$

where $\hat{p}_t$ and P_t are, respectively, the aggregate rate of growth and the level of the sticky prices, and Y_t and Y_t^* are the actual and natural level of output, all measured at time t (unless otherwise mentioned, hereafter we express all variables in log terms and represent growth variables with lower case letters and a hat, and level variables with upper case letters). $E_{t-1}(\cdot)$ represents the expectations operator conditional on information about variables realized up to period t-1, and $L^2(\cdot)$ represents the square of the lag operator. The parameter γ is positive.

Equation (1a) can be derived as a log-linear approximation of the aggregate rate of change of the optimal price of monopolistically competitive producers that set prices in advance at regular intervals and in a staggered fashion. The intuition is as follows. In any period t, half of these producers set a new nominal price that lasts for two periods. This price is chosen to equalize expected marginal revenue with expected marginal cost, given the information about variables realized up to t-1. With constant price-elasticity of individual demands and constant output-elasticity of marginal costs, the new price is set proportional to the expected aggregate price level plus a term equal to the expected gap between aggregate sales and the natural level of output multiplied by a constant coefficient γ. As the new price is set for periods t and t+1, what matters when setting this new price is the expected average of these variables during those two periods (ignoring discounting to simplify). To calculate the rate of change of the aggregate price at period t, it is enough to compute the difference between the new price and the price set by the same producers at t-2, and divide the result by two—as the other half of the producers do not change their price.[6] [7]

Notice that equation (1a) does not allow for unanticipated shocks to affect the relationship between prices and expected output and prices, but does allow for anticipated shocks to affect it. Excluding unanticipated shocks from this relationship is justified because including them would be inconsistent with the assumption that the prices are set on the basis of information about variables realized in previous periods; i.e., it would be inconsistent with the assumption that prices are set in advance. Anticipated shocks, in turn, appear through the term $(½)(1-L^2)E_{t-1}(Y^*_t+Y^*_{t+1})/2$, term which provides the link between those shocks and natural output. The analysis below does not assume a specific form for the stochastic process that drives natural output, except that it is exogenous.

For the analysis below, it is useful to rewrite equation (1a) so as to only include variables measured in rates of change. To do so, one can insert $P_{t+j}=P_{t+j-1}+\hat{p}_{t+j}$, $Y_{t+j}=Y_{t+j-1}+\hat{y}_{t+j}$, and $Y^*_{t+j}=Y^*_{t+j-1}+\hat{y}^*_{t+j}$ for j=0,1, and rearrange terms. The resulting expression is

$$\begin{aligned}\hat{p}_t &= \frac{1}{2}[\hat{p}_{t-1}+\hat{p}_{t-2}+\gamma(\hat{y}_{t-1}-\hat{y}^*_{t-1})+\gamma(\hat{y}_{t-2}-\hat{y}^*_{t-2})] \\ &\quad + \frac{1}{2}(1-L^2)E_{t-1}[\hat{p}_t+\frac{1}{2}\hat{p}_{t+1}+\gamma(\hat{y}_t-\hat{y}^*_t)+\frac{\gamma}{2}(\hat{y}_{t+1}-\hat{y}^*_{t+1})].\end{aligned} \tag{1b}$$

[6]Equation (1a) is a contemporary version of Taylor's (1979, 1980) model of aggregate price adjustment, which merges his assumption that prices (wages in his original work) are fixed periodically in a staggered fashion with the optimal price decisions implied by the monopolistic competition model due to Spence (1976) and Dixit and Stiglitz (1977), as applied to macroeconomic analysis by Blanchard and Kiyotaki (1985). A similar equation has been derived in a number of papers, including among others Ball and Romer (1987), Chari, Kehoe and McGrattan (1996), and King and Wolman (1998). The main difference is that equation (1a) uses Taylor's (1979, 1980) original assumption that prices must be set in advance; i.e., that price decisions for any given period can only be based on information about variables realized up to the previous period. In addition, equation (1a) treats the level of aggregate demand or output as an explicit variable, and expresses the behavior of the aggregate price in terms of rate of change rather than in terms of its level.

[7]Appendix I examines the effects of considering a time-discrete version of the well-known Calvo's (1983) and Rotemberg's (1982) models of sticky-price adjustment, as well as the "P-bar model" recently proposed by McCallum and Nelson (1998).

The second equation of the model is an aggregate demand or "expectational IS" relationship. This establishes that expected spending growth can be expressed as

$$E_t \hat{y}_{t+1} = \sigma (i_t - E_t \pi_{t+1}) - v_t , \tag{2}$$

where $\hat{y}_{t+1}$, i_t, and π_{t+1} respectively denote aggregate spending growth, the level of the nominal interest rate, and the headline (CPI) inflation rate between periods t and t+1, while v_t is a demand shock occurring in period t. The parameter σ is positive.

Equation (2) can be derived as log-linear approximation for the aggregate optimal consumption of households that smooth consumption according to a standard Euler equation, with an intertemporal elasticity of substitution equal to σ, and under the assumption that consumption and spending are equivalent. This equation is consistent with the familiar intuition that current consumption falls relative to expected future consumption when the expected real interest rate rises. The demand shock v_t can be interpreted as an increase in the consumer's subjective rate of discount.[8] [9]

Note that implicit in equations (1a) or (1b) and (2) there is a relationship establishing that in any given period aggregate output is equal to aggregate spending and aggregate income. The equality between aggregate output and aggregate spending follows from the standard assumption that, when prices are sticky, output is driven by demand. This assumption is consistent with the microeconomic model underlying the analysis because, with its price fixed at a level above marginal costs, each monopolistic producer finds it optimal to increase output when demand rises, and to reduce it when demand falls. The equality of aggregate income with aggregate output follows from the assumption of a closed economy.

Finally, as noted above, in the remainder of this section we also assume that headline inflation equals the sticky-prices inflation indicator determined by equation (1a):

$$\pi_t = \hat{p}_t . \tag{3}$$

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[8] A similar equation has been derived and used in recent papers on monetary policy issues, including Bernanke and Woodford (1997), and McCallum and Nelson (1997).

[9] Appendix II examines the effects of considering a more general aggregate demand equation, which adds to the right hand side of (2) a term that depends on current income. It also examines the effects of replacing equation (2) by the assumption that, up to a shock-term, aggregate demand is determined by current real money balances.

B. The Potentially Stabilizing Effects of Inflation Targeting

To close the model presented above, it is necessary to specify an equation for determining the interest rate. In line with the practice of most modern central banks, this and the following two sections assume that the central bank directly uses this variable as its monetary policy instrument; the effects of using the monetary base as the policy instrument are examined in Section IV. Also, the analysis focuses on the effects of an operational rule in which the interest rate set in any given period can be based only on information about variables realized in previous periods. As noted in the introduction, the analysis thus avoids making the assumption that the monetary policymaker can respond to current-period realizations of variables such as GDP and inflation, an assumption that has been used often in the literature, but that has been strongly criticized by McCallum (1993, 1997b). Finally, the analysis concentrates on rational-expectations equilibria in which the monetary policy rule is both credible and has been and is expected to be in place for a sufficiently long time.

In this setting, assume that the central bank chooses in every period the interest rate necessary to maintain the forecast of the (headline and sticky-prices) inflation rate for the following period in line with a target level. If the inflation target is set equal to zero, to simplify notation, the implied interest rate rule is

$$i_t \text{ is such that } E_{t-1}\,\pi_t = 0, \tag{4a}$$

for all t. Note that, as $E_{t-1}\,(E_{t+j-1}\,\pi_{t+j}) = E_{t-1}\,\pi_{t+j}$ for all j = 0,1,2,..., this is equivalent to stating that, under inflation targeting,

$$i_t \text{ is such that } E_{t-1}\,\pi_{t+j} = 0, \tag{4b}$$

for all j=0,1,2,....[10]

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[10]While (4a) or (4b) seems to this author a sensible definition of a monetary policy rule based on inflation targeting (when the policy instrument is the interest rate), Svensson (1997a, 1997b) has defined an inflation targeting rule instead as the monetary policy implied by an objective function that includes inflation and output in its arguments. The definition of inflation targeting used here also differs somewhat from the one used by McCallum and Nelson (1998), according to which inflation targeting occurs when the operational rule for the monetary policy instrument involves some explicit response to deviations of expected inflation from its desired path. From the perspective of the definitions used by the above authors, the definition used in this paper can be interpreted as corresponding to the case of strict inflation targeting.

Taking the expected value of aggregate demand (equation (2)) given information about variables realized up to time t-1, and using the above definition of inflation targeting, it follows that in order to achieve the specified inflation target the central bank should set in every period the interest rate according to the rule

$$i_t = \frac{1}{\sigma}(E_{t-1}\hat{y}_{t+1} + E_{t-1}v_t). \tag{5}$$

Replacing this expression for the interest rate in the expression for actual aggregate demand, implies that changes in demand must obey the equation in differences:

$$E_t\hat{y}_{t+1} = E_{t-1}\hat{y}_{t+1} - (v_t - E_{t-1}v_t), \tag{6a}$$

which can be expressed in terms of changes in the output gap as follows:

$$E_t(\hat{y}_{t+1} - \hat{y}^*_{t+1}) - E_{t-1}(\hat{y}_{t+1} - \hat{y}^*_{t+1}) = -v'_t - u_t, \tag{6b}$$

where v'_t is the unexpected component of the demand shock at time t ($v_t - E_{t-1} v_t$) and u_t is the revision at time t of the expected growth of natural output at t+1 ($E_t \hat{y}^*_{t+1} - E_{t-1} \hat{y}^*_{t+1}$). Note that both v'_t and u_t depend only on shocks realized in period t.

On the supply side, using the definition of inflation targeting given by expression (4a) on equation (3) and (1b) implies

$$\frac{1}{2}[(\hat{y}_{t-1} - \hat{y}^*_{t-1}) + (\hat{y}_{t-2} - \hat{y}^*_{t-2})] + \frac{1}{2}(1-L^2)E_{t-1}[(\hat{y}_t - \hat{y}^*_t) + \frac{1}{2}(\hat{y}_{t+1} - \hat{y}^*_{t+1})] = 0, \tag{7}$$

which makes use of the property that, since the prices are set in advance, and the inflation target has been set equal to zero, then $\hat{p}_t = E_{t-1}\hat{p}_t = 0$ for all t.

It follows that the rate of growth of the output gap must simultaneously obey the expectational difference equations (6b) and (7). The solution to this problem can be found analytically using the method of undetermined coefficients. This method is implemented by first assuming that the solution is of the type $(\hat{y}_t - \hat{y}^*_t) = A(L)v'_t + B(L)u_t$, where A(L), and B(L) are infinite polynomials on the lag operator ($A(L) = a_0 + a_1L + a_2L^2 \ldots$, and $B(L) = b_0 + b_1L + b_2L^2 \ldots$), and then finding the coefficients in A(L), and B(L) that make this solution consistent with equations (6b) and (7). Following this procedure, it is easy to show after some algebra that these coefficients of the lag polynomial must obey the sequences:

$$a_0 = a_0,$$
$$a_1 = -1, \qquad (8a)$$
$$a_n = (-2)^n (1 - a_0) \quad n \geq 2;$$

and

$$b_0 = b_0,$$
$$b_1 = 0, \qquad (8b)$$
$$b_n = (-2)^n (1 - b_0) \quad n \geq 2.$$

Ruling out by assumption explosive solutions, it is possible to set $a_0 = b_0 = 1$. Expressing the implied solution in terms of the level of the output gap, gives

$$\begin{aligned} Y_t - Y_t^* &= v'_t + u_t, \\ &= (v_t - E_{t-1} v_t) + (E_t \hat{y}^*_{t+1} - E_{t-1} \hat{y}^*_{t+1}). \end{aligned} \qquad (9)$$

Equation (9) shows the remarkable result: in the economy being examined, the response of the output gap to aggregate shocks is short lived, limited to the period during which those shocks remain unanticipated.

This is a remarkable result because it is not a general implication of models with staggered price setting but rather a consequence of the assumption that monetary policy is targeting inflation. Indeed, it is well-known from the work of Fischer (1977) and Taylor (1979, 1980) that, in an economy were prices are set in advance for more than one period, the real effects of unanticipated shocks generally can persist for at least as long as the length of the duration of the prices being set, and possibly beyond that when price setting is staggered.[11] By themselves, those results would have led one to expect that the real effects of shocks in the economy being examined could last for at least two periods, and perhaps for longer. In contrast, equation (9) indicates that, under inflation targeting, there is no endogenous persistence in the movements in the output gap in response to unanticipated shocks.

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[11]These results were shown originally by Fischer (1977) and Taylor (1979, 1980) for an economy with sticky wages. For restatements focusing on sticky prices, see Blanchard (1983), and Blanchard and Fischer (1989, ch.8).

The intuition for this result in the case of demand shocks is simple. Demand shocks and monetary policy both affect the economy through their effects on aggregate demand, with for instance a positive demand shock and a reduction in interest rates first tending to increase output, and then gradually to raise prices. Thus, if the central bank designs monetary policy to fully offset the effect of anticipated demand shocks, such a policy should be able to simultaneously stabilize expected inflation and limit the effect on output of the demand shocks to the effect of their unanticipated component.

The finding that a similar result holds in the case of shocks that affect natural output also has a simple explanation. As indicated by equations (1a) and (1b), in any given period, inflation is a function only of past and expected inflation and of the expected average output gap. Thus, in any rational expectations equilibrium, to maintain inflation stable, monetary policy must also maintain the expected average output gap equal to zero. Ruling out by assumption policies that stabilize the average expected output gap but not the output gap expected for each single period, it follows that stabilizing inflation also implies that each period's expected output gap must be equal to zero, or, equivalently, that only current unanticipated shocks can affect the actual output gap.

Note that the interest rate rule needed for this result to hold can be obtained from equations (5) and (9), which jointly imply

$$i_t = \frac{1}{\sigma}(E_{t-1}\hat{y}^*_{t+1} + E_{t-1}v_t). \tag{10}$$

Recalling that we have made the simplifying assumption that the inflation target equals zero, this implies that, to achieve the inflation target, the central bank should set in every period the nominal interest rate equal to the inflation target plus a term that attempts to ensure that the expected growth of aggregate demand between t and t+1 equals the expected growth of natural output. In the model being considered, this requires aligning the interest rate with the ratio between the expected growth of natural output and the intertemporal rate of substitution in demand, and offsetting anticipated demand shocks, as shown in equation (10).

Several remarks are in order. First, the result that under inflation targeting only current unanticipated aggregate shocks would destabilize output implies that inflation targeting can be fully consistent with the systematic attempt on the part of the central bank to eliminate expected output gaps. Indeed, taking expected values at both sides of equation (9) directly implies that inflation targeting requires that the central bank stabilizes the one-period-ahead expected output gap.

Second, while equation (9) shows that inflation targeting can make the effects on the output gap of aggregate shocks short lived, this result does not imply that inflation targeting necessarily minimizes the unconditional variance of the output gap. In principle, there might be some alternative monetary policy rule that, although it implies a longer lasting response of the output gap to those shocks, it reduces the magnitude of the current output gap sufficiently enough as to minimize the unconditional variance of the output gap. This may occur because, under forward looking behavior, the current level of demand is generally a function of the monetary policy rule in place.

Third, as long as monetary policy has some contemporaneous effect on aggregate demand, the essence of the above results does not appear to depend on the specific channel or magnitude of the effect of monetary policy on aggregate demand. It is true that if this effect is small, or if the monetary transmission mechanism is different, then the central bank's attempt to stabilize output and attain the inflation target may require large and unstable adjustments in the value of its policy instrument. However, if prices are determined as assumed in this section, then the essence of the relationship between inflation targeting and output stability will remain the same, regardless of the specification of aggregate demand. For instance, Appendix II shows that this indeed turns out to be the case if one adds to the aggregate demand equation (2) a term that depends on lagged income growth, or if one replaces it by the assumption that, up to a shock term, aggregate demand is determined by real money balances.

Finally, it seems clear that the fundamental element needed to show the above results is that prices are determined as specified in equation (1a), which raises the question about what happens when prices are determined differently. In this regard, some modifications in the modeling of price setting behavior do not change the essence of these results. For instance, Appendix I shows that using a discrete-time version of the price-adjustment models by Rotemberg (1982) and Calvo (1983), usually considered as the main alternatives to the Taylor (1979, 1980) type of model used here, has implications that are similar to the ones discussed above. Similarly, assuming that individual prices last for N periods instead of two periods makes no difference for the above results. Other modifications, however, can have consequences that are more significant. Appendix I, for instance, also shows that using the "P-bar model" recently proposed by McCallum and Nelson (1998) can eliminate the result that inflation targeting makes the effects on the output gap of aggregate shocks short-lived. The reason is that, unlike standard sticky-prices models, their model assumes that it is costly to adjust output, which implies that it is generally optimal that pre-existing output gaps disappear only gradually. Another modification that seems to alters the above results more severely is addressed in the next section.

III. Inflation Targeting in the Presence of Price Shocks

The analysis so far has assumed equality between headline inflation and the sticky-prices inflation rate determined by equation (1a). In practice, however, it is clear that many prices cannot be labeled as sticky; for instance, most commodity and agricultural prices probably would be better characterized by being quite flexible, with their output level adjusting more slowly. Also, many items whose prices affect headline inflation correspond to foreign goods and services whose prices are not directly related to the economy's output gap.

This section explores the effects of allowing for discrepancies between headline inflation and the relevant sticky-prices inflation.

A. Price Shocks and Headline Inflation Targeting

Building on the model developed in the previous section, the simplest way to examine the effects of these discrepancies is to maintain the sticky-prices equation (1a) or (1b) and the aggregate demand equation (2) but to replace equation (3) that links headline inflation and sticky-prices inflation with the relationship

$$\pi_t = \hat{p}_t + w_t, \tag{11}$$

where w_t is an exogenous price shock.

The shock w_t introduced in equation (11) is a price shock only in the sense that, in any given period, it implies a discrepancy between headline inflation and the rate of change of the aggregate sticky prices. While in general the origin of this price shock can be diverse, for the formal analysis that follows, the reader may find it useful to think of this shock as the outcome of an exogenous increase in a general sales tax that is quickly passed into consumer prices, with producer prices being sticky and determined by equation (1b).[12] The advantage of this interpretation is that it provides a straightforward justification for the simplifying assumption that the price shock is exogenous. Alternative interpretations that endogeneize the price shocks are provided and examined in Appendixes III and IV: Appendix III considers a two -sector economy where one sector has sticky prices and the other flexible prices, deriving a price shock that is proportional to the change in the relative price of the two sectors; Appendix IV considers an open-economy in which the implied price shock is proportional to the change in the real price of the imported goods.

Let us thus assume that, in this alternative economy (with equation (11) replacing equation (3)), the central bank targets headline inflation. As the results derived in Section II for the response of the economy to shocks to demand and natural output continue to be valid, it is sufficient to examine the response of the economy to the price shocks; we thus focus on

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[12]In the context of the model being discussed, this interpretation can be easily formalized by introducing into the economy a government with the power to modify taxes and transfers, and asking it to design these changes so as to make them neutral with respect to aggregate demand and natural output. Under the assumption that consumer prices are flexible, while producer prices are sticky, the behavior of the aggregate economy can then be fully characterized equations (1b), (2), (11) and a monetary policy rule. In this case, assuming that the sales tax is ad-valorem, the price shock in any given period is equal to the log change of one plus the sales tax in the same period.

the case $v'_t=u_t=0$. Setting as before the inflation target equal to zero to simplify notation, equation (4a) remains applicable, and using the latter on equation (11), it follows that

$$\hat{p}_t = E_{t-1}\hat{p}_t = -E_{t-1}w_t. \tag{12}$$

Thus, under headline inflation targeting, monetary policy should aim at offsetting the effect on the CPI of anticipated price shocks by eliciting changes in the opposite direction in the aggregate sticky price level.

To explore the consequences on output of this policy rule, assume that $w_t=\epsilon_t+\epsilon_{t-1}$, where ϵ_t is a white-noise shock. Under this specification, it follows that

$$\hat{p}_t = -\epsilon_{t-1}. \tag{13}$$

Replacing equation (13) in the sticky-price equation (1b) implies that output growth must obey the differential equation:

$$-\epsilon_{t-1} + \epsilon_{t-2} = \gamma(\hat{y}_{t-1}+\hat{y}_{t-2}) + \gamma(1-L^2)E_{t-1}(\hat{y}_t+\frac{1}{2}\hat{y}_{t+1}). \tag{14}$$

On the demand side, in turn, equations (4a), (13), and (2) imply that the differential equation for aggregate demand is now

$$E_t\hat{y}_{t+1} = E_{t-1}\hat{y}_{t+1}. \tag{15}$$

To find possible solutions for the behavior of output, let us conjecture that $\hat{y}_t=C(L)\epsilon_t$, where C(L) is an infinite polynomial on the lag operator ($C(L)=c_0+c_1L+c_2L^2\ldots$). Applying again the method of undetermined coefficients to equations (14) and (15) implies that the coefficients of the lag polynomial C(L) must satisfy:

$$\begin{aligned} c_0 &= c_0, \\ c_1 &= 0, \\ c_n &= (-1)^{n-1}[\frac{1}{\gamma}(4(n-2)+2)+2c_0] \quad n\geq 2. \end{aligned} \tag{16}$$

The last row of expression (16) shows that headline inflation targeting can destabilize output dramatically. Indeed, it is easy to see that there is no value for c_0 which prevents the absolute value of c_n from growing linearly with n, with its sign oscillating between negative and positive in any two adjacent periods. What this means is that a single anticipated price in this economy will cause output to fluctuate in non converging and ever widening boom-and-recession cycles.

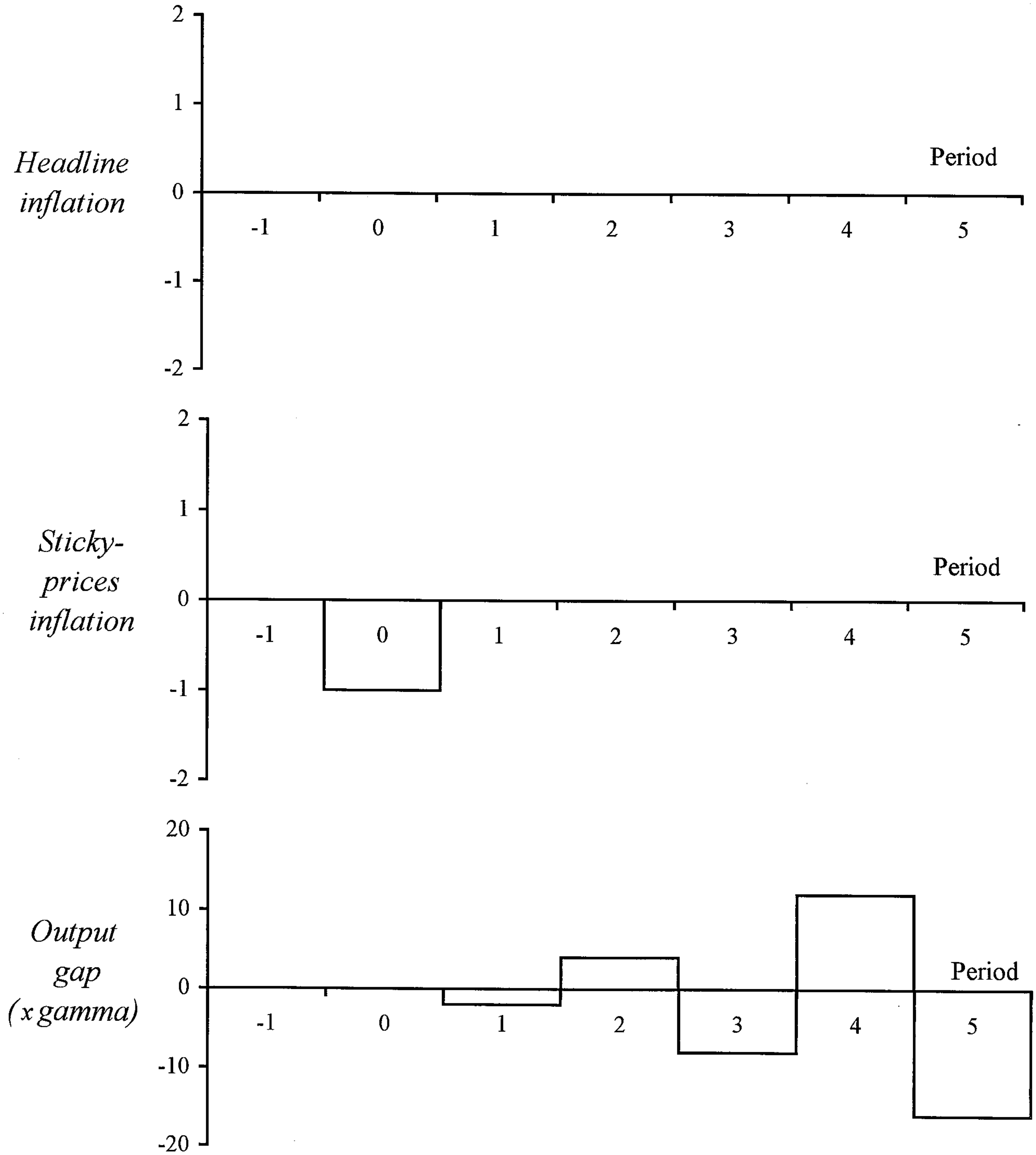
To illustrate this result, consider the solution (16) for c_0=0, and suppose that at t=-1 there is a shock ϵ_{-1}=1 which anticipates the occurrence of a unit price shock one period ahead. Figure 1 depicts the implied behavior of headline inflation, sticky-prices inflation, and the output gap. At t=0, to ensure stability of the CPI, half of the firms must cut their prices by twice the size of the shock. This, however, can only be achieved if these firms expect that the average output gap during the period in which they will maintain fixed their new prices is negative (this could also happen if the firms expect the prices of their competitors to fall, but the latter would be inconsistent with inflation targeting). As the current output gap is zero, it follows that the output gap at t=1 must be negative. This, however, is not the end of the story. At t=1, the reduction in the prices of competitors in the previous period tend to push down the prices of the other half of the firms. To prevent a new round of price cuts, as inflation targeting requires, it follows that monetary policy should aim to create a positive average output gap during the period in which these other firms maintain their prices fixed. As the output gap at t=1 is negative, it follows that the output gap at t=2 must be positive and larger in magnitude than the output gap at t=1. Repeating this reasoning for subsequent periods, it is easy to see that attaining the inflation target following a single anticipated price shock requires ever larger boom-recession cycles.

While the above example focuses on the effects of a single anticipated price shock, it is clear that if one allows for an infinite sequence of those shocks, the effects of headline inflation targeting can be even more dramatic. Formally, it is easy to check that the coefficients for C(L) in expression (16) imply that the unconditional variance of the rate growth of the output gap tends to infinity.

This results merits some comments or qualifications. An obvious one is that the extreme output instability generated by headline inflation targeting in this economy should not be taken as a realistic prediction of the effects of introducing headline inflation targeting in an actual economy. Apart from the trivial point that reality is more complex than any simple model, it would be reasonable to expect that the structure of an economy such as the one considered here would change. For instance, it is likely that the central bank would abandon its inflation targeting policy, or that the producers would modify their price setting behavior.

More important, it should be noted that in reality most price shocks are likely to be endogenous. As shown in Appendix III, when the relationship between the CPI and the sticky-prices depends on other variables in the economy, the potentially destabilizing effects of headline inflation targeting on output may either intensify or dampen. On the one hand, allowing for an endogenous price shock implies that any type of shock perturbing the

Figure 1. Targeting Headline Inflation: Effects of a Unit Anticipated Price Shock



economy under headline inflation targeting can lead to severe output instability, including for instance the shocks to aggregate demand and natural output that in the simple model presented above create no serious threat for output instability under headline inflation targeting. On the other hand, allowing for an endogenous price shock also implies that, depending on the specific structure of the economy, there can be values for the economy's parameters for which the severe instability problems associated with headline inflation targeting disappear. Unless these parameter values are such that they generally make the expected output gap nil, however, targeting headline inflation generally will not imply that the output gap depends only on current unanticipated shocks, as in the previous section.

B. Targeting Sticky-Prices Inflation

Given that the problem of excessive output instability brought about by targeting headline inflation stems from the discrepancies between the inflation indicator being targeted and the sticky-prices inflation indicator determined by equation (1a), an obvious solution would seem to be to target the latter. To examine the implications of this policy, we replace (4a) by the condition

$$i_t \textit{ is such that } E_{t-1}\hat{p}_t = 0. \tag{17}$$

Using this condition and equations (1b), (2) and (11) yields the following solution for the output gap:

$$\begin{aligned} Y_t - Y_t^* &= (v_t - E_{t-1}v_t) + (E_t\hat{y}^*_{t+1} - E_{t-1}\hat{y}^*_{t+1}) + \sigma(E_t w_{t+1} - E_{t-1}w_{t+1}), \\ &= v'_t + u_t + \sigma w'_t \end{aligned} \tag{18}$$

where w'_t is the revision at time t of the price shock expected at t+1 ($E_t w_{t+1} - E_{t-1} w_{t+1}$).

Equation (18) shows that targeting sticky-prices inflation restores the earlier finding that inflation targeting can ensure that only current unanticipated shocks destabilize output. This result arises because targeting such an indicator relieves monetary policy from the burden of trying to offset the effect of anticipated price shocks with changes in the sticky prices. And as discussed in the previous section, under rational expectations, stabilizing the sticky prices of the economy is fully compatible with stabilizing the expected output gap.

Notice that the only difference between equation (18) and equation (9) derived earlier for analyzing the effects of inflation targeting in the absence of price shocks is that now the current output gap also depends on the news about future price shocks (w'_t). This shock term enters expression (18) because, for a given interest rate, news about future price shocks affect the expected real interest rate. The interest rate rule associated with this solution is

$$i_t = \frac{1}{\sigma}(E_{t-1}\hat{y}^*_{t+1} + E_{t-1}v_t) + E_{t-1}w_{t+1}; \qquad (19)$$

i.e., the interest rate rule derived above (equation (10)) is modified to allow for interest rate adjustments when the central bank anticipates price shocks that may destabilize aggregate demand through their effect on the expected real interest rate.

Once again, several remarks are in order. First, as shown in Appendices III and IV, the essence of the result contained in equation (18) can also be obtained from more complicated settings, with two sectors in the economy, and openness to international trade and financial transactions respectively. Of course, the output gap associated with sticky-price inflation targeting under these alternative settings depend on different sets of shocks, including for instance supply shocks in the sector with flexible prices (Appendix III), and shocks in the long run real exchange rate (Appendix IV). In both cases, however, the end result is that sticky-prices inflation targeting solves the instability problem posed by headline inflation targeting and shields the output gap from anticipated shocks.

Second, the result that targeting a sticky-prices inflation indicator eliminates the potentially destabilizing effects of headline inflation targeting appears to be consistent with the fact that, in practice, some inflation-targeting central banks target an inflation indicator that excludes from the CPI the prices of some of the goods with more volatile behavior, such as oil, food, and others, with some of these central banks also excluding from the CPI the effects of changes in indirect taxes (see Bernanke, Laubach, Mishkin, and Posen, 1999). Besides providing a formal justification to this practice, the analysis in this section and in the appendices sheds some light on the type of adjustments needed: the appropriate indicator should exclude the prices of goods with very flexible prices—particularly the prices of goods that in the short-term are in fixed supply—as well as the price of goods with sticky prices that are not directly linked to the domestic output gap—such as the prices of imported goods.

Third, as finding an appropriate sticky-prices inflation indicator might be difficult in practice, the result contained in equation (18) also might help explain why actual inflation targeting regimes leave significant room for discretionary monetary policy, as explained in Bernanke, Laubach, Mishkin, and Posen (1999).

Finally, the caveats noted in Section II regarding the effects of headline inflation targeting in the absence of discrepancies between headline inflation and sticky-prices inflation also apply to this case. For instance, it should be clear that limiting the time-horizon of the response of the output gap to destabilizing shocks is not equivalent to minimizing the unconditional variance of the output gap.

IV. The Monetary Base as Policy Instrument

The analysis so far has assumed that the policy instrument used to implement inflation targeting is the interest rate. While this assumption is consistent with the practice of most modern central banks, the old issue of which is the best monetary policy instrument has not yet been settled.[13] This section explores whether the result that targeting sticky-prices inflation can ensure that only unanticipated shocks destabilize output is robust to the use of the monetary-base as policy instrument. In addition, it explores the conditions under which an inflation targeting regime designed to stabilize output should be implemented using the monetary base or the interest rate as its monetary policy instrument, and shows the form of the policy rule when the chosen instrument is the monetary base.

For the analysis in this section, it is assumed that the economy presented in the previous sections also possesses a standard demand for the monetary base. This is written in terms of rate of changes as follows:

$$\hat{m}_t \;=\; \pi_t + \hat{y}_t - \beta(1-L)\, i_t + z_t, \tag{20}$$

where $\hat{m}_t$ is the rate of change of the demand for monetary base, z_t an exogenous shock on the demand for monetary base, and β a positive parameter measuring the interest-rate elasticity of the demand for monetary base. Also, it is assumed below that, in any given period, the interest rate adjusts to balance the demand for monetary base with the monetary base supplied by the central bank.

In the light of the results obtained in the previous sections, it is most interesting to focus on the effects of a monetary-base rule that targets sticky-price inflation. Specifically, we now consider a rule where

$$\hat{m}_t \textit{ is such that } E_{t-1}\hat{p}_t = 0. \tag{21}$$

Using equations (20), (21) and (12) it is easy to show that the market interest rate that makes the demand and supply for monetary base equal must satisfy:

$$i_t \;=\; \frac{1}{\beta}\left(w_t - E_{t-1}w_t + \hat{y}_t - E_{t-1}\hat{y}_t + z_t - E_{t-1}z_t\right). \tag{22}$$

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[13] At least in academic discussions; for instance, see McCallum (1997a).

Replacing the expression for the interest rate given by (22) in the equation for aggregate demand (2), and using (11), (21), and some algebra implies that the rate of change of the output gap must obey the differential equation

$$E_t(\hat{y}_{t+1} - \hat{y}^*_{t+1}) - E_{t-1}(\hat{y}_{t+1} - \hat{y}^*_{t+1}) = \frac{\sigma}{\beta}[\hat{y}_t - \hat{y}^*_t - E_{t-1}(\hat{y}_t - \hat{y}^*_t)] - v'_t - u_t - \sigma w'_t$$
$$+ \frac{\sigma}{\beta}(\hat{y}^*_t - E_{t-1}\hat{y}^*_t + w_t - E_{t-1}w_t + z_t - E_t z_{t-1}), \tag{23}$$

where, as before, v'_t, u_t, and w'_t are respectively the unexpected component of the demand shock at time t, the revision at time t of the expected growth in natural output at t+1, and the revision at time t of the expected value of the price shock at t+1.

On the supply side, the relevant price equation is the same one considered in Section III for the case of an interest rate rule. Therefore, the solution for the output gap must simultaneously solve equations (23) and (7). Using the method of undetermined coefficients once again, and ruling out explosive solutions, yields the following solution for the level of the output gap:

$$Y_t - Y*_t = \frac{\beta}{\sigma+\beta}(v'_t + u_t + \sigma w'_t) - \frac{\sigma}{\sigma+\beta}(\hat{y}^*_t - E_{t-1}\hat{y}^*_t + w_t - E_{t-1}w_t + z_t - E_{t-1}z_t). \tag{24}$$

Equation (24) shows that a monetary base rule that targets sticky-prices inflation can ensure that only current unanticipated shocks destabilize output, a finding similar to the one obtained for an interest rate rule that targets the same indicator.

In addition, the comparison of equation (24) with equation (18) allows to establish the conditions under which the monetary base or the interest rate should be the preferred instrument in an inflation targeting regime that also attaches a positive value to output stability. In the most general case, these conditions follow from assessing whether the structural parameters of the economy and the stochastic processes of the shocks being considered make the unconditional variance of the right hand side of equation (18) smaller or larger than the right hand side of equation (24). For space reasons, we do not undertake here a detailed analysis of those conditions and focus instead on the implications of having each type of the shock predominate.

If demand or monetary shocks predominate, it is straightforward to check that the conditions for the choice of instrument implied by equations (18) and (24) are similar to those implied by Poole's (1970) well-known analysis: when unanticipated demand shocks prevail, the monetary base is the preferred policy instrument (as $\beta/(\sigma+\beta)<1$); when unanticipated monetary shocks prevail, the interest rate is the preferred policy instrument (as $\sigma/(\sigma+\beta)>0$); when the demand and monetary shocks are anticipated, the choice of instrument is irrelevant. That these results hold in the present model is not very surprising, since in the absence of price shocks, the inflation targeting rule being considered guarantees Poole's assumptions that the price level is exogenous.[14]

If unanticipated price or natural output shocks predominate, in turn, the comparison of equations (18) and (24) indicates straightforwardly that output stability is enhanced by an interest rate rule (as $\sigma/(\sigma+\beta)>0$). This result stems from the fact that, under the inflation targeting regime being considered, the appropriate adjustment of the economy when these types of shocks occur requires proportional changes in the current CPI or in the current level of output. While an interest rate rule permits full accommodation of the changes in the demand for monetary base implied by these adjustments, a monetary base rule forces excessive fluctuations in the market interest rate, and thus destabilizes output.

In the case where anticipated price or natural output shocks predominate, it is easy to check from equations (18) and (24) that news about these shocks can be better dealt with a monetary base rule. The reason is that, although these news affect the expectations about future inflation identically when using a an interest rate rule or a monetary base rule, the expected real interest rates changes less under a monetary base rule, as the shift in current aggregate demand induced by the change in expected inflation is dampened by a parallel adjustment in interest rates due to the short-term fixity of the supply of the monetary base.

Finally, note that the explicit form of the policy rule implied by sticky-prices inflation targeting when the chosen instrument is the monetary base (using (11), (20), (21), and (22)) is

$$\hat{m}_t = E_{t-1}\hat{y}_t^* + (\hat{y}_{t-1}^* - E_{t-2}\hat{y}_{t-1}^*) + E_{t-1}w_t + (w_{t-1} - E_{t-2}w_{t-1}) + E_{t-1}z_t + (z_{t-1} - E_{t-2}z_{t-1}); \qquad (25a)$$

i.e, the central bank should accommodate the effects on the demand for monetary base of anticipated natural output, price, and monetary shocks, as well as the effects of past forecasting errors on the same variables. A simpler formulation of this rule can be obtained by integrating backwards and normalizing equation (25a), which permits to rewrite it as

[14]The underlying intuition is the standard one: a monetary base rule implies an automatic and partially offsetting adjustment of interest rates in response of unanticipated demand shocks, while an interest rate rule permits to fully accommodate unanticipated shocks in the demand for the monetary base; also, the effect of anticipated demand and monetary shocks can be fully offset by appropriate changes in the chosen instrument.

$$M_t = E_{t-1}(Y_t^* + W_t + Z_t), \tag{25b}$$

where M_t and Y^*_t are the level of the monetary base and natural output, and W_t and Z_t are cumulative sums of the price and monetary shocks introduced above. In words, the implied monetary base rule is one that attempts to accommodate the expected level of demand for monetary base, evaluated at the natural level of output and the sticky-prices inflation target.

VI. Concluding Remarks

The wisdom of conducting short-term monetary policy so to attain an inflation target often is questioned on the grounds that it could lead to undesirable output fluctuations. The analysis in this paper shows that, in an economy with sticky prices, targeting headline inflation indeed can severely destabilize output in the presence of anticipated price shocks. The reason is that targeting this type of indicator implies that monetary policy must try to offset the effect of anticipated price shocks on headline inflation with changes in the opposite direction in the sticky prices of the economy. Engineering these price changes requires destabilizing the expected output gap, and thus also the actual output gap.

The analysis, however, also implies that inflation targeting and output stabilization may be made compatible by targeting an inflation indicator that relieves monetary policy from the burden of trying to offset the effect of anticipated price shocks on headline inflation. The appropriate inflation indicator for that purpose would be one that focuses on the prices of the goods with sticky prices and that directly depend on the expected output gap, excluding, for instance, the prices of goods in fixed supply and the prices of imported goods. The above analysis suggests that aiming at such an indicator may eliminate the threat for output stability implied by targeting a broader inflation indicator, and greatly reduce the persistence of the movements in the output gap in response to aggregate shocks.

As in most of the analytical literature in the field, the analysis in this paper focuses on the effects of monetary policy on the gap between actual and natural output. This is a crucial element for evaluating the welfare consequences of alternative monetary policy rules, as in any second order approximation of the utility function of households, a main distinctive effect of each of these rules is likely to come from its impact on the variability of this gap, which affects both the variability of consumption and employment. Nonetheless, a complete evaluation of the welfare consequences of monetary policy rules would require considering additional effects, including, for instance, the impact of the alternative rules on the average level of output, and on intra and intertemporal price fluctuations.

Even when focusing only on output stability, the analysis can be extended in several directions. For instance, it was noted above that limiting the time-horizon of the effects on the output gap of aggregate shocks is generally not the same as minimizing output instability; thus even from this viewpoint, the search for the optimal monetary policy is open. Also, it would be of interest to explore the effects of inflation targeting in an economy with state-dependent price setting and/or with multisectorial and asymmetric price staggering. Perhaps most important, the issue whether targeting an operational sticky-prices inflation indicator actually stabilizes output relative to alternative monetary policies only can be assessed from an empirical vantage point. At a minimum, this paper shows that any analysis of that type should take into account that the effects of inflation targeting on output stability can be highly sensitive to the specific inflation indicator being targeted.

The Potentially Stabilizing Effects of Inflation Targeting with Alternative Models of Sticky Prices

This Appendix examines the effects of inflation targeting on output stability when all prices are sticky (as in Section II of the main body of the paper), but considering alternative models for the adjustment of the sticky prices.

First, we examine the effects of considering a discrete-time version of the well-known models of price adjustment proposed by Calvo (1983), which assumes staggered price setting and random duration of price decisions, and Rotemberg (1982), which assumes quadratic costs of adjusting prices. Roberts (1995) has shown that, while the underlying rationale of those models differ, they both imply a discrete-time price adjustment equation of the form:

$$\hat{p}_t = E_t \hat{p}_{t+1} + \gamma (Y_t - Y_t^*), \qquad \text{(A1)}$$

where the notation is similar to the one used in the main text.

Replacing equation (1a) with equation (A1) and maintaining the rest of the basic equations presented in Section II, the effects of considering this alternative model of sticky-price adjustment can be obtained by finding out the solutions that simultaneously satisfies equation (A1) and equation (6b). It is easy to check that, under inflation targeting and the assumption that all prices are sticky, an admissible solution to that system is

$$Y_t - Y_t^* = v'_t + u_t, \qquad \text{(A2)}$$

where, as in the main text, v'_t is the unexpected component of the demand shock at time t ($v_t - E_{t-1} v_t$) and u_t is the revision at time t of the expected growth of natural output at t+1 ($E_t \hat{y}^*_{t+1} - E_{t-1} \hat{y}^*_{t+1}$).

Notice that equation (A2) is identical to equation (9) in the main body of the paper. Therefore, using a discrete-time version of the Calvo (1982) and Rotemberg (1983) models does not alter the basic result in Section II that, when all prices are sticky, inflation targeting can make the response of the output gap to aggregate shocks short-lived.

Second, we examine the effects of considering the "P-bar" price adjustment model recently proposed by McCallum and Nelson (1998). Unlike standard sticky-prices models, that model assumes that there are costs of adjusting the output gap. In addition, it assumes that there are costs of adjusting prices, that prices are set in advance for one period, and that, ex-post, output always adjusts to meet demand. By specifying the costs of adjusting prices and the output gap as being quadratic on the (log) rate of change of those variables, the model leads to the following differential equations:

$$E_{t-1}(P_t - \bar{P}_t) = \phi(P_{t-1} - \bar{P}_{t-1}), \tag{A3}$$

$$E_{t-1}(Y_t - \bar{Y}_t) = \phi(Y_{t-1} - \bar{Y}_{t-1}), \tag{A4}$$

where $\bar{P}_t$ and $\bar{Y}_t$ are the price and output levels that would exist in the absence of any costs of adjusting price or output, and if prices do not need to be set in advance. The parameter ϕ that appears in both equations is smaller than unity and positive, unless there are no costs of adjusting output, in which case it equals zero.

Under the assumption that $Y_t^* = \bar{Y}_t$, it is easy to check (using (A4) and equation (6b)) that under this alternative sticky-price adjustment model, an admissible solution to the model presented in Section II is

$$Y_t - Y_t^* = \phi(Y_{t-1} - Y_{t-1}^*) + \frac{1}{1-\phi}(v'_t + u_t), \tag{A5}$$

where v'_t and u_t are the same shock terms defined above.

Except in the special case that there are no costs of adjusting output, the first term at the right hand side of equation (A5) implies that the response of the output gap to aggregate shocks is not short-lived in this model. The precise interpretation of this result is unclear, however, because, under quadratic costs of adjusting prices and output, it is optimal that pre-existing output gaps disappear only gradually. Or put somewhat differently, it is not clear whether the deviations of output from $\bar{Y}_t$ provide the relevant measure of the output gap.[15]

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[15]Another difficulty of this model is that it is not evident how to reconcile its assumption that ex ante there are quadratic costs of adjusting output with its assumption that ex post, output always adjust to satisfy demand, regardless of the size of the shocks that hit the economy.

The Potentially Stabilizing Effects of Inflation Targeting with Alternative Models of Aggregate Demand

This Appendix examines the effects of inflation targeting on output stability when all prices are sticky (as in Section II of the main body of the paper), but considering alternative models for aggregate demand.

First, we examine the effects of considering a more general specification of aggregate demand, which adds on the right hand side of equation (2) a term that depends on current output growth as follows:

$$E_t \hat{y}_{t+1} = (1-\lambda)\sigma(i_t - E_t \pi_{t+1}) + \lambda \hat{y}_t - v_t, \tag{B1}$$

where the parameter λ is nonnegative and smaller than unity, and the remainder of the notation is similar to the one used in the main text.

The introduction of the term $\lambda \hat{y}_t$ in this equation can be seen as the result of the assumption that part of the households in the economy consume in each period the income they received in the previous period. That consumption rule can be justified, for instance, as the consequence of liquidity constraints, under the hypothesis that income is paid at the end of each period and is thus available for consumption only during the next period. With the auxiliary assumption that those households receive a fixed proportion of aggregate income, equation (B1) can be derived as the approximate weighted average of the expected growth of consumption of the households that follow that rule, and the expected growth of consumption of the households that smooth consumption with an intertemporal elasticity of substitution equal to σ. Under this interpretation, λ should be understood as the fraction of total income accrued to the households that consume lagged income.

Replacing equation (2) with equation (B1) and maintaining the rest of the basic equations presented in Section II, the effects of considering this alternative model of aggregate demand can be obtained by finding out the solutions that simultaneously satisfies equation (B1) and equation (7). It is easy to check that, under inflation targeting and the assumption that all prices are sticky, an admissible solution to that system is

$$Y_t - Y_t^* = \frac{1}{1+\lambda}(v'_t + u_t - \lambda u'_t), \tag{B2}$$

where, as in the main text, v'_t is the unexpected component of the demand shock at time t ($v_t - E_{t-1} v_t$) and u_t is the revision at time t of the expected growth of natural output at t+1 ($E_t \hat{y}^*_{t+1} - E_{t-1} \hat{y}^*_{t+1}$). Also, by definition, the shock term u'_t corresponds to the unexpected component of the shock in natural output at time t ($\hat{y}^*_t - E_{t-1} \hat{y}^*_t$).

Notice that equation (B2) is identical to equation (9) in the main body of the paper when the parameter λ is equal to zero. For other admissible values for λ, in turn, equation (B2) indicates that the effect of the demand shocks v'_t and the revisions about future natural output shocks u'_t are smaller than in equation (9), a result which is a natural consequence of the assumption now that part of the households consume an amount which is independent of current developments. The latter also explains the appearance of the new shock term u'_t, as it implies that when there are surprises that increases in current natural output, part of the consumers do not automatically increase their current level of consumption.

More important for the purposes of this paper, equation (B2) shows that adding a term that involves current income to the aggregate demand equation (2) does not alter the basic result that, when all prices are sticky, inflation targeting can ensure that only unanticipated shocks destabilize output. Or in other words, that inflation targeting can make the effects on output of aggregate shocks short-lived.

Second, we examine the effects of replacing equation (2) by the assumption that, up to a shock term, aggregate demand is determined by the level of current real money balances. To simplify, we also assume here that the central bank directly controls money supply. Thus we have

$$\hat{y}_t = \hat{m}_t - \pi_t - z_t, \tag{B3}$$

and

$$\hat{m}_t \text{ is such that } E_{t-1}\pi_t = 0, \tag{B4}$$

where $\hat{m}_t$ is the rate of change of money supply, and z_t an exogenous shock on the inverse of the velocity of money.

Using (B3), (B4), (3) and taking into account that $\hat{p}_t = E_{t-1}\hat{p}_t$, it is easy to show that under this specification for aggregate demand

$$(\hat{y}_t - \hat{y}_t^*) - E_{t-1}(\hat{y}_t - \hat{y}_t^*) = -z'_t - u'_t, \tag{B5}$$

where z'_t is the unexpected component of the shock z_t at time t ($z_t - E_{t-1} z_t$) and, as before, u'_t is the unexpected component of the shock in natural output at time t ($\hat{y}^*_t - E_{t-1}\hat{y}^*_t$).

The effects of considering this alternative model for aggregate demand can be obtained by finding out the solutions that simultaneously satisfies equation (B5) and equation (7). It is easy to check that an admissible solution to that system is

$$Y_t - Y_t^* = -z'_t - u'_t. \tag{B6}$$

Equation (B6) indicates that now the fluctuations in the output gap are caused by current unanticipated shocks in the velocity of money and in natural output, which are different in nature from the shocks that appear in the analysis in the main body of the paper. Nonetheless, equation (B6) shows that, even if aggregate demand is assumed to be determined by real money balances, it is still the case that inflation targeting can make the response of the output gap to aggregate shocks short-lived.

Inflation Targeting in a Two-Sector Economy

This appendix examines some of the implications of considering a simple economy that, in addition to a productive sector with sticky prices and demand-determined output, has a productive sector with flexible prices and exogenous output.

The notation in this appendix is as follows. As in the main text, $\hat{y}_t$, π_t, $\hat{p}_t$, and i_t denote the rate of growth of output in the sticky-prices sector, headline inflation, sticky-prices inflation, and the nominal interest rate, respectively. The new endogenous variables are $\hat{p}_t^f$, which denotes flexible-prices inflation, and $\hat{a}_t$, which denotes the rate of growth of an aggregate demand index that combines the demands for the goods in the sticky and flexible-price sectors according to a CES specification. The shock variables are $\hat{y}_t^f$, $\hat{y}_t^*$, v_t, which respectively represent actual output in the flexible prices sector, natural output in the sticky prices sector, and a shock in aggregate demand. Regarding the parameters, σ continues to denote the intertemporal elasticity of substitution in aggregate demand, while θ denotes the intratemporal elasticity of substitution in the demand for the sticky prices and the flexible goods, and α the share of the sticky-prices sector in total output and consumption.

We approximate the aggregate behavior of this two-sector economy with the log-linear equations:

$$E_t \hat{a}_{t+1} = \sigma (i_t - E_t \pi_{t+1}) - v_t, \tag{C1}$$

$$\hat{y}_t - \hat{y}_t^f = \theta (\hat{p}_t^f - \hat{p}_t), \tag{C2}$$

$$\pi_t = \alpha \hat{p}_t + (1-\alpha) \hat{p}_t^f, \tag{C3}$$

$$\hat{a}_t = \alpha \hat{y}_t + (1-\alpha) \hat{y}_t^f, \tag{C4}$$

plus equation (1b) for the sticky prices, and the interest rate rule applied by the central bank. By assumption, the parameter values obey the restrictions: $\sigma>0$, $\theta>0$, and $0<\alpha<1$.

Using equations (C2) and (C3) in equation (C1) implies that demand for the sticky-prices goods can be written as:

$$E_t\hat{y}_{t+1} = \frac{\sigma}{1-\phi}(i_t - E_t\hat{p}_{t+1}) - \frac{\phi}{1-\phi}E_t\hat{y}^f_{t+1} - \frac{1}{1-\phi}v_t, \tag{C5}$$

where we assume that $\phi \equiv (\sigma-\theta)(1-\alpha)\theta^{-1}$ is different from unity. Note that this equation resembles aggregate demand equation (2), but with different coefficients and an additional shock term coming from the supply shock in the sector with flexible prices.

Also, equations (C2) and (C3) imply that

$$\pi_t = \hat{p}_t + \frac{(1-\alpha)}{\theta}(\hat{y}_t - \hat{y}^f_t), \tag{C6}$$

where the second term of the right hand side of this equation corresponds to the now endogenous price shock, which depends on the relative growth of output in the sticky-prices and the flexible-prices sectors.

The effects of targeting sticky-prices inflation on the output-gap can be found using the same procedure used in the main text. It is easy to show that this procedure leads to the following solution

$$Y_t - Y^*_t = \frac{1}{1-\phi}(v_t - E_{t-1}v_t) + (E_t\hat{y}^*_{t+1} - E_{t-1}\hat{y}^*_{t+1}) + \frac{\phi}{1-\phi}(E_t\hat{y}^f_{t+1} - E_{t-1}\hat{y}^f_{t+1}). \tag{C7}$$

Thus the basic result that only current unanticipated shocks destabilize the output gap under sticky-price inflation targeting holds. The implied behavior of headline inflation can be computed from equation (C7) and (C6), and using the property that under sticky-price inflation targeting $\hat{p}_t = E_{t-1}\hat{p}_t = 0$.

Regarding the effects of headline inflation targeting, note that equation (4a) and equation (C6) imply that under this monetary policy regime the central bank must attempt to influence sticky prices so that:

$$\hat{p}_t = \frac{(1-\alpha)}{\theta}(E_{t-1}\hat{y}^f_t - E_{t-1}\hat{y}_t). \tag{C8}$$

Thus, in this economy, a monetary policy rule based on headline inflation targeting will put pressure on the sticky-prices both when there are anticipated shocks in the supply of the good with flexible prices, as well as when there are anticipated changes in the output of the sticky-prices sector. The latter implies that even shocks in aggregate demand or in natural output in the sticky prices sector may lead to severe output instability.

The potentially destabilizing effects of headline inflation targeting can be shown as follows. The first step is to use equation (C8) in the sticky prices equation (1b) to obtain an expectational difference equation for the output gap stemming from the supply side, and to use the definition of headline inflation targeting (4a) on equations (C5) and (C6) to obtain an expectational difference equation for the output gap stemming from the demand side. The second step is to use the method of undetermined coefficients on these two equations to find the restrictions that they impose on the form of the possible solutions. Focusing, for instance, on the effect of the demand shocks $v'_t=(v_t - E_{t-1} v_t)$, one can assume that $\hat{y}_t=D(L)v'_t$, where D(L) is an infinite polynomial on the lag operator ($D(L)=d_0+d_1L+d_2L^2...$), and then derive the implied restrictions on the coefficients of D(L). Except in the particular case in which $1-\alpha-\gamma\theta=0$, which is discussed below, implementing this procedure leads to a set of linear equations relating d0, d1, d2, d3, d4, and the condition that, for all $n\geq 4$, the coefficients d_n must obey the differential equation $d_n-2\lambda d_{n-1}+d_{n-2}=0$, where $\lambda\equiv(1-\alpha+\gamma\theta)(1-\alpha-\gamma\theta)^{-1}$. The third step is to check that one of the roots for the characteristic equation associated to the latter equation is always larger than unity in absolute value, while the other can be larger or smaller than unity in absolute value depending on the economy's parameter values: this result implies that, in the general case, the only way to always find a convergent solution for the coefficients of D(L) would be to have $d_n=0$ for all $n\geq 4$. The final step is to verify that the latter condition is generally incompatible with the form of the linear equations for d0, d1, d2, and d3 obtained in step number two: as this incompatibility implies that such a convergent solution does not always exist, it follows that, in the general case, headline inflation targeting can severely destabilize output when demand shocks occur. A similar proof can be implemented for the case of shocks in the supply of the flexible-prices sector and in the natural output of the sticky-prices sector.

The above analysis makes it clear that allowing for an endogenous price shock can worsen the problems of headline inflation targeting for output stability, as in the economy being discussed even shocks in aggregate demand and in natural output in the sticky-prices sector can lead to severe output instability. However, the same endogeneity of the price shock also implies that there are parameter values of the economy for which the severe instability problems associated to headline inflation targeting can disappear. In particular, under the simplifying assumption that the supply shocks in the sector with flexible prices cannot be anticipated two periods in advance ($E_{t-1}\hat{y}^f_{t+1}=0$ for all t), it can be shown that if $1-\alpha-\gamma\theta=0$, then

$$Y_t - Y_t^* = \frac{2}{1-\phi}(v_t - E_{t-1}v_t) + \frac{2}{1-\phi}(v_{t-1} - E_{t-2}v_{t-2}) + 2(E_t\hat{y}_{t+1}^* - E_{t-1}\hat{y}_{t+1}^*)$$
$$+ (E_{t-1}\hat{y}_t^* - E_{t-2}\hat{y}_t^*) + \frac{1+\phi}{1-\phi}E_t\hat{y}_{t+1}^f + \frac{1}{1-\phi}E_{t-1}\hat{y}_t^f. \tag{C9}$$

Therefore, although targeting headline inflation under these parameter values does not imply that the output gap depends only on current unanticipated shocks, it also does not lead to the severe output instability problems that headline inflation targeting can generate under other parameter values.

Inflation Targeting in an Open Economy

This appendix explores some of the implications of considering a simple economy open to international trade and financial transactions. The focus is on the effects of inflation targeting when there are shocks to aggregate demand, natural output, and the expected long-run real exchange rate. To simplify, the analysis assumes that the international price of imported goods and the international interest rate are constant. Also, the analysis assumes that all the production of the sector with sticky prices is consumed domestically, and that the price of the imported good in terms of domestic currency is set one period in advance.

The notation in this appendix is as follows. As in the main text, $\hat{y}_t$, π_t, $\hat{p}_t$, and i_t denote the rate of growth of output in the sticky-prices sector, headline inflation, sticky-prices inflation, and the nominal interest rate respectively. The new endogenous variables are $\hat{p}_t^m$, which denotes imported goods inflation (measured in domestic currency); $\hat{s}_t$, which represents the rate of devaluation of the domestic currency; $\hat{imp}_t$, which denotes the rate of change of imports, and $\hat{a}_t$, which denotes the rate of growth of an aggregate demand index that combines the demands for the goods of the sticky-price sector and the imported good according to a CES specification. The shock variables are v_t, $\hat{y}_t^*$, and ρ_t, which respectively represent shocks that affect aggregate demand, natural output in the sticky prices sector, and the (perceived) long-run real exchange rate. Regarding the parameters, σ continues to denote the intertemporal elasticity of substitution in aggregate demand, while θ denotes the intratemporal elasticity of substitution in the demand for the sticky-prices and the imported goods, and α the share of the sticky-prices sector in total consumption.

We approximate the aggregate behavior of the variables in this open economy with the log-linear equations:

$$E_t \hat{a}_{t+1} = \sigma (i_t - E_t \pi_{t+1}) - v_t, \tag{D1}$$

$$\hat{y}_t - \hat{imp}_t = \theta (\hat{p}_t^m - \hat{p}_t), \tag{D2}$$

$$\pi_t = \alpha \hat{p}_t + (1-\alpha) \hat{p}_t^m, \tag{D3}$$

$$\hat{a}_t = \alpha \hat{y}_t + (1-\alpha) \hat{imp}_t, \tag{D4}$$

$$\hat{p}_t^m = E_{t-1} S_t - E_{t-2} S_{t-1}, \tag{D5}$$

$$E_t \hat{s}_{t+1} = i_t, \tag{D6}$$

$$\lim_{j\to\infty} E_t(S_{t+j} - P_{t+j}) = \rho_t, \tag{D7}$$

plus equation (1b) for the sticky prices, and the interest rate rule applied by the central bank. By assumption, the shock ρ_t follows a random walk and the parameter values satisfy the restrictions: $\sigma>0$, $\theta>0$, and $0<\alpha<1$. Note that equations (D5) and (D6) implicitly assume the law of one price for the price of the imported goods, and perfect capital mobility, with the log of the international price of the imported good and the international interest rate conveniently set equal to zero.

Using equations (D2), (D3) and (D4) in equation (D1) implies that demand for the sticky-prices goods can be written as:

$$E_t \hat{y}_{t+1} = \sigma(i_t - E_t \hat{p}_{t+1}) - \psi(E_t \hat{p}^m_{t+1} - E_t \hat{p}_{t+1}) - v_t, \tag{D8}$$

where we assume that $\psi \equiv (\sigma-\theta)(1-\alpha)$ is different from σ. Note that this equation is similar to equation (2) but with a second term which captures the effects on the changes in the relative prices of the imported and the domestic good. Also, equation (D3) implies that

$$\pi_t = \hat{p}_t + (1-\alpha)(\hat{p}^m_t - \hat{p}_t), \tag{D9}$$

which shows that the now endogenous price shock depends on the difference between imported inflation and domestic sticky-prices inflation.

Equations (D8) and (D9) cannot be used directly to examine the effects of an interest rate rule because they include imported inflation, an endogenous variable. Note, however, that (D5), (D6) and (D7) imply

$$\hat{p}^m_t = i_{t-1} + S_{t-1} - E_{t-2} S_{t-1}, \tag{D10}$$

with

$$S_t = \rho_t - \sum_{j=0}^{\infty} E_t i_{t+j}. \tag{D11}$$

To examine the effects of targeting sticky-prices inflation on the output-gap, equations (D10), (D11), and the condition $E_{t-1}\hat{p}_t=0$ for all t can be used on equations (D8) and the sticky prices equation (1b) to obtain a system of equations on the (rate of change of the) output gap and interest rate. It is easy to check that a valid solution to this system is:

$$Y_t - Y_t^* = (v_t - E_{t-1}v_t) + (E_t\hat{y}_{t+1}^* - E_{t-1}\hat{y}_{t+1}^*) + \psi(\rho_t - E_{t-1}\rho_t) + \frac{\psi}{\sigma - \psi}(\kappa_t - E_{t-1}\kappa_t), \qquad \text{(D12)}$$

where the shock term

$$\kappa_t \equiv \sum_{j=1}^{\infty} E_t(v_{t+j} - \hat{y}_{t+j}^*) \qquad \text{(D13)}$$

summarizes the effects of anticipated shocks in aggregate demand and natural output (in the domestic sticky-prices sector) on the expected path of future interest rates (given the inflation targeting rule) and thus on the current exchange rate.

Given the nature of the terms in the right hand side of equation (B12), it follows that the result that only current unanticipated shocks destabilize the output gap under sticky-price inflation targeting also holds in this economy. The implied behavior of headline inflation can be computed from equations (D8) to (D12), and the property that under sticky-price inflation targeting $\hat{p}_t=E_{t-1}\hat{p}_t=0$.

Regarding the effects of targeting headline inflation, note that equation (4a) and equation (D9) imply that under this monetary policy regime the central bank must attempt to influence sticky prices so that:

$$\hat{p}_t = -\frac{(1-\alpha)}{\alpha} E_{t-1}\hat{p}_t^m. \qquad \text{(D14)}$$

Thus, in this economy, a monetary policy rule based on targeting headline inflation must put pressure on the sticky-prices when there are anticipated changes in import prices. As implied by equations (D11) and (D12), the latter can happen in response of any shocks affecting the actual or expected exchange rate and interest rates, including shocks to the expected long run real exchange rate as well as shocks to aggregate demand, or to natural output in the domestic sticky prices sector. While we do not attempt to find a closed form solution for this economy in this appendix, given the results already obtained in the main body of the paper and in Appendix III, the potentially destabilizing effects of headline inflation targeting in this economy are apparent.

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