

# Monetary policy in the presence of asymmetric wage indexation

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Abstract: We study optimal monetary policy in the presence of asymmetric wage indexation. We find that the monetary authorities do not react to small output shocks and that their reaction to large shocks is asymmetric. As a consequence, we observe that asymmetric wage indexation can be recessionary and that it decreases the inflationary bias relative to an equivalent symmetric indexation.

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## 1. Introduction

The study of the reaction functions of central banks has attracted a lot of attention from both academics and practitioners over the recent years, leading to a flourishing literature that has accumulated fresh evidence. Among the fresher results stands the fact that monetary policy tends to be asymmetric. Namely, it is not adjusted in the same way in the presence of positive or adverse shocks. This observation initially made by Mishkin and Posen (1997) and Clarida and Gertler (1997) was later confirmed by Dolado et al. (2000). Thus it appears that major central banks tend to react more aggressively when inflation exceeds its target level than when it is below it.

This finding is clearly at odds with most of the theoretical work on monetary policy, which, in the spirit of Barro and Gordon (1983), usually assumes that symmetric central banks with symmetric preferences face symmetric economies. To depart from the perfect symmetric world that is usually depicted in theoretical contributions, and provide a rationale for observed stylised facts, some authors explicitly introduced an asymmetry in the preferences of the monetary authority they were modelling. Thus, the recent papers by Dolado et al. (2000), Gerlach (2000), Cukierman (2000), Jordan (2001), or Cukierman and Gerlach (2002) all assume that the monetary authorities' loss function is asymmetric. Namely, they assume that positive and negative deviations of economic variables from their target levels impact differently on the central banker's utility.

Asymmetric preferences is however not the only asymmetry that may interfere with the conduct of monetary policy. In fact monetary authorities are confronted with many asymmetries, the most obvious of which being the economy itself. Thus, Cover (1992) observes that negative monetary growth shocks in the United States induce large contractions in real output growth whereas positive monetary shocks have only limited expansionary consequences. Moreover, Kandil (1995, 1998, 2002) repeatedly observed similar asymmetries in various samples of countries both developed and developing.

A likely culprit for those asymmetries is wage indexation, since wages are typically indexed upward but not downward. Such an observation was for instance made by Card (1986) for North American wages. Moreover, Kandil (1995, 1998) observed asymmetric reactions of nominal wages to monetary shocks at the aggregate level. In a more recent paper Kandil (2002) traces the evolution of the United States' performance back to the variations in the downward rigidity and upward flexibility of nominal wages. Those empirical observations were recently complemented by Cover and VanHoose (2002)'s contribution. These authors show that asymmetric wage indexation can be the result of a rational behaviour of the private sector. Namely, they show that the private sector can choose to index nominal wages upward but not downward.

In this paper we also tackle the issue of asymmetric wage indexation from a theoretical point of view. However, instead of focusing on the explanation of that phenomenon, we concentrate on its consequences for monetary policy. Our paper therefore complements the literature devoted to the impact of wage indexation on monetary policy, that was pioneered by Ball and Cecchetti (1991), Vanhoose and Waller (1991, 1992) or Milesi-Ferretti (1994). That literature shows that wage indexation can be welfare enhancing because, even though it may raise the variability of output in the

presence of real shocks, it cuts down the inflationary bias of monetary policy. Surprisingly it has only focused on symmetric wage indexation. Due to the policy implications of that strand of research, it is important to check the robustness of its results in the light of a more realistic framework. This is the aim of the present paper.

We find that the assumption of asymmetric wage indexation, although it leads to greater analytical complexity, significantly modifies the results of the literature. More precisely, we observe that the monetary authorities do not react to all output shocks and most of all that they adopt an asymmetric monetary policy rule. Accordingly, they tend to absorb expansionary shocks more than recessionary ones, which is in line with the stylised fact underlined above. That behaviour can moreover result in an expected level of income that falls short of its natural level. We also find that asymmetric wage indexation lowers expected inflation, which is a standard result of the literature. However, we find that it leads to lower average inflation than symmetric indexation.

To reach those conclusions, the rest of the paper is organised as follows: the next section presents the simple set-up on which our reasoning rests. The following section describes the monetary authorities' behaviour. Section 4 closes the model and compares the outcome of monetary policy in the presence of asymmetric wage inflation with the outcomes of monetary in the presence of symmetric wage indexation or no indexation. Section 5 concludes.

## 2. The set-up

To describe the supply side of our model, we suppose that output is a downward-sloping schedule of the real wage. When all variables are expressed in logs, the supply function reads:

$$y_t = -(w_t - p_t) + u_t \quad (1)$$

Where  $y_t$  is output,  $w_t$  the nominal wage,  $p_t$  the price level.  $\alpha$  is a positive constant.  $u_t$  is a real shock, the magnitude of which is unknown to workers when they sign their wage contracts.  $u_t$  is i.i.d. and has a zero mean and a well defined variance  $\sigma_u^2$ .

The nominal wage is supposed to follow a modified Gray (1976) indexation rule. Namely, and following Cover and VanHoose (2002), we assume that wages are indexed upward but not downward. Therefore, the indexation rule reads:

$$w_t = p_t^e + \mathbf{d}(p_t - p_t^e) \quad (2)$$

where  $0 \leq \mathbf{d} \leq 1$  if  $p_t > p_t^e$  and  $\mathbf{d} = 0$  if  $p_t = p_t^e$ .

$\mathbf{d}$  is the indexation parameter and  $p_t^e$  the expected price level. When the observed price level exceeds the expected price level, the nominal wage is therefore a weighted average of current and expected price levels. It is fully indexed when  $\mathbf{d} = 1$ . On the other hand, when the expected price level overshoots the observed price level, the nominal wage remains fixed. In other words, we assume that the nominal wage is automatically adjusted upward but is sticky downward.<sup>1</sup>

Following Kandil (1998), there are several ways to justify the asymmetric indexation rule we employ here. The first one is to assume that it is the result of an institutional setting that only encourages upward adjustment in nominal wages. It would for instance not be counterintuitive to consider that firms allow nominal wages to increase during booms to keep up with price rises while they are reluctant to fire workers in times of recession, due to high hiring costs. Secondly, in countries marked by a history of high inflation workers may be more concerned about underestimating than overestimating the inflation rate. They would thus demand an indexing rule that would prevent large reductions of the real wage but would consider real wage increases unlikely. Finally, one may also contend that asymmetric indexation rules are an optimal response to real and nominal uncertainties. Cover and VanHoose (2002) thus demonstrate that possibility.

When (2) is plugged into (1), the supply function is transformed into an expectations-augmented short-run Phillips curve:

$$y_t = (1 - \mathbf{d})(\mathbf{p}_t - \mathbf{p}_t^e) + u_t \quad (3)$$

Where  $\mathbf{p}_t$  and  $\mathbf{p}_t^e$  are period  $t$ 's current and rationally expected inflation. Expression (3) shows that the slope of the trade-off between income and unexpected inflation is a decreasing function of the indexation parameter  $\mathbf{d}$  whenever current inflation exceeds expected inflation. However, the slope of the supply curve is strictly greater when current inflation does not exceed or is equal to its expected level, as wages are not indexed downward. This means that the supply curve is kinked, which will have dramatic consequences on the behaviour of the monetary authority, as we will see below.

To model the demand side, we simply assume that the inflation rate is set directly by a monetary authority whose loss function is similar to Barro and Gordon (1983)'s:

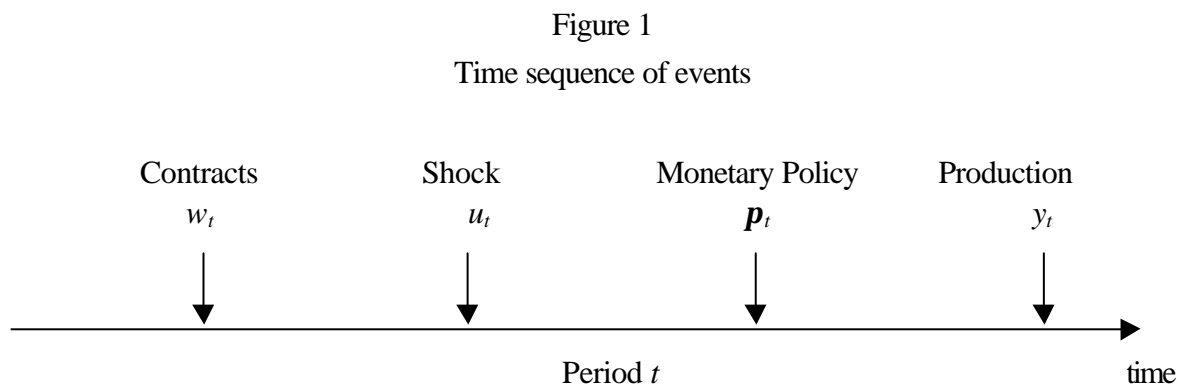
$$l_t = \frac{\mathbf{q}}{2} \mathbf{p}_t^2 + \frac{1}{2} (y_t - \bar{y})^2 \quad (4)$$

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<sup>1</sup> This is clearly a simplification. Our results would nevertheless remain qualitatively unchanged if we assumed

$\bar{y}$  is the target level of output which can be greater than the natural level of income due to distortions on the labour market.  $q$  measures the relative weight the authorities place on output stabilisation versus inflation stabilisation.

To complete the description of our model, we must specify the timing of events. We therefore assume that workers sign their wage contracts at the beginning of period  $t$ . The value of the real shock  $u_t$  is then revealed. The authorities subsequently set the inflation rate accordingly. Finally, production takes place.



### 3. The authorities' reaction function

When monetary policy is discretionary and players move sequentially, the only time consistent policy can be determined by backward induction. As workers play first we must therefore determine the authorities' reaction function for a given nominal wage.

When the authorities set the inflation rate, they have already observed the nominal wage, and the supply shock. Accordingly, they minimise the value of their loss function (4) subject to (3) for a given level of  $p_t^e$  and  $u_t$ . Taking first order condition, we can determine an expression of the authorities' reaction function when the price level exceeds its expected value:

$$p_t = \frac{(1-d)^2 p_t^e + (1-d)\bar{y} - (1-d)u_t}{q + (1-d)^2} \quad \text{if } p_t > p_t^e \quad (5a)$$

One can immediately get an expression of the reaction function of the authorities when the price level is smaller than the expected inflation rate by setting  $d = 0$  in (5a). One consequently gets:

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instead that wages are less indexed downward than upward.

$$\mathbf{p}_t = \frac{\mathbf{p}_t^e + \bar{y} - u_t}{\mathbf{q} + 1} \quad \text{if } p_t = p_t^e \quad (5b)$$

Of course, expressions (5a) and (5b) do not provide a complete description of the behaviour of the authorities. We must indeed determine under which circumstances they will implement an inflation rate that is higher or lower than expected. In other words, we must determine the magnitude of the shock that will lead the authorities to set  $\mathbf{p}_t > \mathbf{p}_t^e$  or  $\mathbf{p}_t = \mathbf{p}_t^e$ . To do so, we substitute  $\mathbf{p}_t$  by its value in (5a) and solve the resulting inequality for  $u_t$ . It then appears that the authorities will choose  $\mathbf{p}_t > \mathbf{p}_t^e$  if (and only if)  $u_t$  is smaller than a trigger value  $\underline{u}$  such that:

$$\underline{u} = \bar{y} - \frac{\mathbf{q}}{1 - \mathbf{d}} \mathbf{p}_t^e \quad (6a)$$

By the same token, and using expression (5b), we find that the authorities will set  $\mathbf{p}_t = \mathbf{p}_t^e$  if and only if  $u_t$  is smaller or equal to a trigger value  $\bar{u}$  such that:

$$\bar{u} = \bar{y} - \mathbf{q} \mathbf{p}_t^e \quad (6b)$$

We assume that the parameters of the model are such that they result in a positive expected inflation.<sup>2</sup> Since we assume that  $\mathbf{d}$  is smaller than one, it is clear that  $\bar{u} > \underline{u}$ . Therefore, if the reaction of the authorities is well defined for shocks smaller than  $\underline{u}$  or greater than  $\bar{u}$ , we do not know yet what their reaction may be in between. However, we show in the appendix that their best response whenever  $u_t \in [\underline{u}; \bar{u}]$  is to set an inflation rate that is equal to the expected inflation rate.

We can now give a precise definition of the reaction function of the authorities. It reads:

$$\mathbf{p}_t = \begin{cases} \frac{(1-\mathbf{d})^2 \mathbf{p}_t^e + (1-\mathbf{d})\bar{y} - (1-\mathbf{d})u_t}{\mathbf{q} + (1-\mathbf{d})^2} & \text{if } u_t < \underline{u} \\ \mathbf{p}_t^e & \text{if } \underline{u} < u_t < \bar{u} \\ \frac{\mathbf{p}_t^e + \bar{y} - u_t}{\mathbf{q} + 1} & \text{if } u_t > \bar{u} \end{cases} \quad (7)$$

From this expression of the reaction function, we can reach our first proposition:

Proposition 1: The authorities do not accommodate small shocks.

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<sup>2</sup> It is in fact possible that expected inflation turns out negative as, as we will see below, the authorities tend to react more to positive output shocks than to negative ones.

Proof: From (7) it is clear that whenever  $u_t \in [\underline{u}; \bar{u}]$ , there is no unexpected inflation and the authorities therefore do not absorb the supply shock, which proves proposition 1.

\*\*\*insert figure 1 here\*\*\*

The intuitive explanation of proposition 1 is easily grasped by looking at figure 1. As the supply curve is kinked, we obtain corner solutions when shocks belong to the  $[\underline{u}; \bar{u}]$  interval. It takes a larger shock to drive the optimal inflation rate above or below  $p^e$ .

Proposition 2: The authorities accommodate large inflationary output shocks more than large recessionary shocks

Proof: By plugging the relevant part of (7) in (3), one obtains the actual value of output for a given expected inflation rate when the authorities behave according to their reaction function.

It amounts to  $y_t = \frac{-q(1-d)p_t^e + (1-d)^2 \bar{y}}{q+1} - \frac{q}{q+(1-d)^2} u_t$  whenever  $u_t < \underline{u}$  and to

$y_t = \frac{-qp_t^e + \bar{y}}{q+1} - \frac{q}{q+1} u_t$  whenever  $u_t > \bar{u}$ . The coefficient on  $u_t$  indicates the elasticity

of output to the initial shock. As  $d$  is positive and smaller than one, it appears that the absolute elasticity of output to shock  $u_t$  is greater when the shock is negative than when it is positive, which proves proposition (2).

The intuition behind proposition 2 is fairly straightforward. The authorities determine the inflation rate by comparing the marginal loss incurred by increased inflation and the marginal benefit from bringing output closer to its target level. Now, as wages are indexed upward but not downward, the marginal benefit of manipulating inflation is smaller for negative output shocks, that require to inflate more than expected and face wage indexation, than for positive output shocks that require to inflate less than expected. Therefore the incentive to manipulate inflation is smaller for negative shocks than for positive shocks. The former are consequently less accommodated than the latter.

The results we have obtained so far do not necessitate to determine expected inflation. However, determining expected inflation is a necessary step to describe the outcome of monetary policy in our model. We turn to that step in the next section.

## 4. Expectations, Output and Welfare

When private agents form their expectations about the inflation rate, they do not know the magnitude of the inflation rate. They therefore ignore if the authorities will manipulate inflation and how. They must consequently expect an average of the conditional expectations of the inflation rates weighted by their probabilities. Accordingly, the private sector expects the following inflation rate:

$$\mathbf{p}_t^e = \text{prob}(u_t < \underline{u}) \cdot E(\mathbf{p}_t | u_t < \underline{u}) + \text{prob}(\underline{u} < u_t < \bar{u}) \cdot E(\mathbf{p}_t | \underline{u} < u_t < \bar{u}) + \text{prob}(u_t > \bar{u}) \cdot E(\mathbf{p}_t | u_t > \bar{u}) \quad (8)$$

The first step in solving equation (8) is to compute the conditional expectations and probabilities of the inflation rate, which requires to specify the distribution of  $u_t$ . In the rest of the paper, we assume that it is normally distributed around zero. For conciseness sake, the conditional probabilities and expectations are defined in appendix (A2). By substituting those values in expression (8) and by simplifying, one obtains an equation whose solution is the expected inflation rate. Unfortunately, that equation is quite messy and has no simple solution. In the rest of this paper, we therefore resort to simulations to close the model.

Table 1 reports the results of our simulations for a realistic range of the parameters. It exhibits the expected value of the inflation rate, of output and of the authorities' losses. It also displays the inflation rate that would be expected if wage indexation was symmetric, that is denoted  $\mathbf{p}_{sim}^e$ , and with no indexation, that is designated by  $\mathbf{p}_{noindex}^e$ .<sup>3</sup>

Although the results displayed in table 1 rest on a simulation and cannot therefore be generalised, they confirm some standard results of the literature. Namely, it appears that a larger targeted level of output and a smaller weight attached to inflation increase the inflationary bias. This results from the fact that both these evolutions increase the perceived benefit from unexpected

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<sup>3</sup> Those inflation rates are given by  $\mathbf{p}_{sim}^e = \frac{1-d}{q} \bar{y}$  and  $\mathbf{p}_{noindex}^e = \frac{1}{q} \bar{y}$  respectively. The expected output in the presence of symmetric indexation is always equal to the natural level of output which is zero in our set-up and is therefore not reported.

inflation. As the private sector understands the incentives faced by the authorities, the inflationary bias.

Table 1 : simulation results

	$s$	$\bar{y}$	$q$	$d$	$s$	$p^e$	$E(y)$	$E(l)$	$p^{e\ noindex}$	$p^{e\ simm}$
	(1)	(2)	(3)	(4)	(1)	(5)	(6)	(7)	(8)	(9)
(1)	1	1	1	0.5	1	0.112	-0.015	0.204	1	0.5
(2)	1	1	1	0.9	1	0.025	-0.060	0.236	1	0.1
(3)	1	1	1	0.1	1	0.149	0.050	0.157	1	0.9
(4)	1	1	0.5	0.1	1	0.219	0.099	0.118	2	1.8
(5)	1	1	0.5	0.5	1	0.195	0.017	0.180	2	1
(6)	1	1	2	0.5	1	0.060	-0.035	0.220	0.5	0.25
(7)	1	1	5	0.5	1	0.025	-0.048	0.230	0.2	0.1
(8)	1	0.5	1	0.5	1	0.051	-0.024	0.095	0.5	0.25
(9)	1	2	1	0.5	1	0.255	0.053	0.654	2	1
(10)	1	4	1	0.5	1	0.543	0.183	2.446	4	2

Beside those usual results, our simulations highlight two important findings that are summarised in our next propositions and are worth underlining.

Proposition 3a : Asymmetric wage indexation can be recessionary.

Proposition 3b : Asymmetric wage indexation can be expansionary.

That striking feature of our simulations is obtained by reading the sixth column of table 1 and appears in lines (1), (2), (6), (7) and (8). The intuition of this result rests on proposition 2. As the authorities absorb positive shocks more than negative ones, it is possible that output lies on average below its natural level. It need not be so though. Thus, this finding depends on the magnitude of the shocks that are stabilised and on the probability that they occur, which explains why expected output may lie above its natural level, as in lines (3), (4), (5), (9) and (10) of table 1.

A slightly more careful inspection of table 1 reveals a second set of noteworthy findings that are summarised in proposition 4a and 4b.

Proposition 4a: Asymmetric wage indexation can reduce the inflationary bias relative to a situation without indexation.

This finding is obtained by comparing columns (5) and (8) of table 1. It appears that the inflationary bias, alternatively expected inflation is systematically lower in the presence of asymmetric wage indexation than in the presence of no indexation at all. This finding is in line with the common view of the consequences of wage indexation on monetary policy, that can for instance be traced back to Devereux (1987). It results from the fact that wage indexation lowers the perceived benefits from unexpected inflation because it reduces its impact on the real wage. The temptation to inflate is therefore cut down accordingly.

Proposition 4b: Asymmetric wage indexation can reduce the inflationary bias relative to an equivalent symmetric indexation.

That proposition is more innovative. It is obtained by comparing columns (5) and (9) of table 1. It underlines that there is more to asymmetric indexation than a simple combination of symmetric indexation and no indexation. To grasp the rationale behind proposition (4b), one must bear in mind that we are dealing with a stochastic model and that wage indexation interacts with both the deterministic component of the inflation rate and its stochastic component. Namely it reduces the inflationary bias but also modifies the way the authorities adjust the inflation rate so as to absorb output shocks.

Now, when indexation is symmetric, it cuts down the inflationary bias but has a symmetric impact on the reaction of the authorities to output shocks. In other words it reduces the incentive to engineer unexpected inflation but also to engineer unexpected disinflation, when shocks are very expansionary. On average, both effects cancel out.

When indexation is asymmetric however, it also cuts down the inflationary bias but it only reduces the incentive to create unexpected inflation and leaves intact the incentive to create unexpected disinflation. This asymmetry in the reaction of the authorities to output shocks further

reduces the average inflation rate, which explains why expected inflation is even smaller than in the presence of symmetric wage inflation.

## 5. Concluding remarks

In this paper, we studied the consequences of asymmetric wage indexation for monetary policy in a framework à la Barro and Gordon (1983). We observed that that marginal modification of their framework provides unexpected modifications of the usual findings of the literature. Namely, we found that the reaction of monetary authorities to output shocks could become asymmetric, leading to an expected level of output that may be below its natural level. We also found that if wage indexation is deflationary, it is more so when it is asymmetric. A synthetic theoretical implication of our findings is that making our models slightly more realistic can significantly alter the results that are usually considered standard in the literature.

The main policy implication of our results is that wage indexation is more subtle a policy instrument and that its effects are more pervasive than what is usually contended in the literature. Owing to the complexity of our calculations, we had to resort to numerical simulations and cannot unfortunately be more specific as to the critical values of the parameters. Our results accordingly deserve closer examination, which paves the way for future research. However, in the mean time, they remain, to say the least, intriguing.

## Appendix

### *A1 Monetary policy when $u_t \in [\underline{u}; \bar{u}]$*

In this appendix, we show that the optimal monetary policy when  $u_t \in [\underline{u}; \bar{u}]$  consists in validating the private sector's expectations. Our line of reasoning is organised in two steps. We firstly show that it is not optimal for the authorities to implement an inflation rate that exceeds expected inflation. We then show that it is not optimal to implement an inflation rate that is lower than expected inflation.

Let us assume that the authorities implement an inflation rate that exceeds expected inflation. Under those circumstances, wages are indexed and the supply function is given by (3). To determine the optimal inflation rate, we plug (3) in (4) and differentiate. We thus get the following expression:

$$\left. \frac{\partial l}{\partial \mathbf{p}_t} \right|_{d \in [\underline{u}; \bar{u}]} = (1 - \mathbf{d})^2 (\mathbf{p}_t - \mathbf{p}_t^e) + (1 - \mathbf{d})(\bar{y} - u_t) + \mathbf{q}\mathbf{p}_t$$

(A1)

As we assume that the inflation rate that the authorities implement is greater than the expected inflation rate, it is clear that the first member of expression (A1) is positive. It can easily be shown that the second member of that expression is also positive. Thus, as we assume that  $u_t \in [\underline{u}; \bar{u}]$ , we know from (6a) that  $u_t > \bar{y} - \frac{\mathbf{q}}{1 - \mathbf{d}} \mathbf{p}_t^e$ . This is equivalent to:

$$(1 - \mathbf{d})(u_t - \bar{y}) > -\mathbf{q}\mathbf{p}_t^e \quad (\text{A2})$$

By adding  $\mathbf{q}\mathbf{p}_t$  to both sides of the above inequality and factorising, one finds:

$$(1 - \mathbf{d})(u_t - \bar{y}) + \mathbf{q}\mathbf{p}_t > \mathbf{q}(\mathbf{p}_t - \mathbf{p}_t^e) > 0$$

(A3)

As we assume that  $\mathbf{p}_t > \mathbf{p}_t^e$ , expression (A3), that is equal to the second part of expression (A1), is clearly positive, meaning that the authorities' losses are increasing in  $\mathbf{p}_t$ . The authorities' optimal solution is consequently a corner solution and they set  $\mathbf{p}_t = \mathbf{p}_t^e$ .

By the same token, we can show that the authorities will not set an inflation rate that is lower than the expected inflation. Under those circumstances, wages are not indexed and the supply function is given by (3) with  $\mathbf{d} = 0$ . To determine the optimal inflation rate, we plug (3) in (4) and differentiate. We thus get the following expression:

$$\left. \frac{\partial l}{\partial \mathbf{p}_t} \right|_{d=0} = \mathbf{p}_t - \mathbf{p}_t^e - \bar{y} + u_t + \mathbf{q}\mathbf{p}_t \quad (\text{A4})$$

As we assume that the inflation rate that the authorities implement is smaller than the expected inflation rate, it is clear that the first member of expression (A4) is negative. It can easily be shown that the second member of that expression is also negative. Thus, as we assume that  $u_t \in [\underline{u}; \bar{u}]$ , we know from (6a) that  $u_t < \bar{y} - \mathbf{q}\mathbf{p}_t^e$ , which is equivalent to:

$$u_t - \bar{y} < -\mathbf{q}\mathbf{p}_t^e \quad (\text{A5})$$

By adding  $\mathbf{q}\mathbf{p}_t$  to both sides of the above inequality and factorising, one finds:

$$u_t - \bar{y} + \mathbf{q}\mathbf{p}_t < \mathbf{q}(\mathbf{p}_t - \mathbf{p}_t^e) < 0 \quad (\text{A6})$$

As we assume that  $\mathbf{p}_t < \mathbf{p}_t^e$ , expression (A6) shows that the second member of expression (A4) is clearly negative, meaning that the authorities' losses are decreasing in  $\mathbf{p}_t$ . The authorities' optimal solution is consequently a corner solution and they set  $\mathbf{p}_t = \mathbf{p}_t^e$ .

Consequently, whenever  $u_t \in [\underline{u}; \bar{u}]$ , the authorities' optimal policy is to implement the inflation rate that was expected by the private sector. They consequently do not accommodate the supply shock.

## A2 Conditional expectations and probabilities

As  $u_t$  follows a normal distribution, the conditional probabilities on  $u_t$  can be written as:

$$\text{prob}(u_t < \underline{u}) = \int_{-\infty}^{\underline{u}} f du \quad \text{prob}(\underline{u} < u_t < \bar{u}) = \int_{\underline{u}}^{\bar{u}} f du \quad \text{prob}(u_t > \bar{u}) = \int_{\bar{u}}^{\infty} f du$$

(A7a)

(A7b)

(A7c)

where  $f = \frac{1}{\mathbf{p}\sqrt{2\mathbf{s}}} e^{-\frac{u^2}{2\mathbf{s}}}$  is the normal density function.

By the same token, the conditional expectation of the inflation rate can be written as:

$$E(\mathbf{p}_t | u_t < \underline{u}) = \int_{-\infty}^{\underline{u}} f \cdot \mathbf{p}_t | u_t < \underline{u} du \quad (\text{A8a})$$

$$E(\mathbf{p}_t | \underline{u} < u_t < \bar{u}) = \int_{\underline{u}}^{\bar{u}} f \cdot \mathbf{p}_t | \underline{u} < u_t < \bar{u} du \quad (\text{A8b})$$

$$E(\mathbf{p}_t | u_t > \bar{u}) = \int_{\bar{u}}^{\infty} f \cdot \mathbf{p}_t | u_t > \bar{u} \, du \quad (\text{A8c})$$

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