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Credible Purchases of Credibility Through Exchange Rate Pegging: An Optimal Taxation Framework

BERTHOLD HERRENDORF

European University Institute, Florence

EUROPEAN UNIVERSITY INSTITUTE, FLORENCE

ECONOMICS DEPARTMENT

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BERTHOLD HERRENDORF

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Badia Fiesolana
I – 50016 San Domenico (FI)
Italy

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An Optimal Taxation Framework*

BERTHOLD HERRENDORF
European University Institute
e–mail: herrendo@datacomm.iue.it

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Abstract

We consider the time consistency problem of monetary policy in an open economy when inflation is in part uncontrollable due to stochastic disturbances. If these disturbances are private information of the government, individuals cannot discover whether the government is responsible for realized inflation surprises. As is standard this leads to an inflationary bias in a reputational equilibrium when inflation is targeted. We show that pegging the exchange rate eliminates this bias if the foreign authority is precommited. However, since generally the foreign inflation rate is domestically suboptimal, only a properly designed crawling peg is guaranteed of improving welfare.

KEYWORDS: Asymmetric Information; Credibility; Exchange Rate Pegging; Optimal Inflation Taxes; Time Consistency.

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1 Introduction

One important feature of a pegged nominal exchange rate regime is its disinflationary potential, given that one country in the system has achieved relatively stable prices. This has been widely recognized in the literature, which was mostly focused on the European experience. A first formalization of the disinflation properties of the EMS was offered by Giavazzi and Pagano (1988), who essentially applied an idea of Rogoff (1985) to a two country world. Within a closed economy Rogoff suggested the employment of a conservative central banker, who is overly averse to inflation, in order to eliminate the inflationary bias of the discretionary equilibrium, arising when the monetary authority does not have access to a precommitment technology. Obviously this solution is only applicable when the central banker enjoys enough institutional independence from the government to actually run the central bank according to his preferences.[1] In contrast when he is dependent on the government, Giavazzi and Pagano (1988) suggest that a conservative central banker can indirectly be employed by setting up a fixed exchange rate system with a foreign country that has managed to eliminate its discretionary inflation bias, for example, like Germany by itself having established an independent central bank.

This argument has frequently been used to explain the disinflation process that some of the EMS–participants have experienced.[2] However, as realignments are still possible, the EMS is not a fixed but rather a pegged nominal exchange rate regime.[3] While irrevocably fixed nominal exchange rates are credible per definition, the credibility of a pegged nominal exchange rate system needs to be justified endogenously.[4] As is familiar from the literature on time consistency, a nominal exchange rate peg will be called credible if the decision to follow the pegged system is found to be time consistent.

The credibility issue of pegged exchange rate regimes has not been ad-

[1] An institutional reform that achieves sufficient central bank independence may be rather difficult to pass through the legislative system and is therefore not discussed here.

[2] See for example Currie, Levine and Perlman (1992).

[3] A pegged nominal exchange rate system can be either a fixed peg or a crawling peg, depending on whether the ex ante announced rate of nominal exchange rate depreciation is equal to zero. The difference between a pegged and a fixed exchange rate systems is that the former is adjustable.

[4] Irrevocably fixed exchange rates arise, for example, when a country's fixed exchange vis–a–vis a center country's currency is written into its constitution. An historical example is Sweden during the gold standard.

equately addressed analytically in the literature on exchange rate systems. Common practice is either to assume credibility or to offer some ad–hoc explanations for it.[5] For example, it has frequently been argued that the credibility of the EMS stems from the credibility of the participants' commitment to the eventual economic and monetary integration implied by the process towards European Union. The commitment was considered to be credible because of "wider European political objectives", which led to substantial changes in the participating countries' policy stances [Goodhart (1990)]. The fact that no realignment had occurred between January 1987 and August 1992 seemed to support this view.[6] However, when the uncertainty regarding the ratification of the Maastricht Treaty surfaced and the ERM experienced a dramatic crisis in September 1992, considerable doubt regarding the prospect for monetary integration in Europe arose.[7] Alternatively, the loss of an *international* reputation as a consequence of reneging on a pegged exchange rate may lead to a reduced incentive to cooperate with the reneging authority in the future, perhaps in other areas than exchange rate management. Some authors, including Obstfeld (1991) and Rasmussen (1993), have therefore assumed a fixed exogenous cost of reneging on an exchange rate announcement, which may be avoided through reneging on a domestic target.[8]

These arguments, while intuitively appealing, are essentially ad hoc in nature and few formal attempts to model reputation in order to explain the credibility of an exchange rate regime have been made.[9] However, while reputational forces may explain why it is optimal for policy makers to do without unexpected devaluations, a sound theoretical explanation as to why pegging the exchange rate should in any sense be preferable to targeting the inflation rate has not yet been offered. Usually this issue is avoided. For example, de Kock and Grilli (1993) (implicitly) assume that the policy of targeting the ex ante optimal domestic inflation rate is not credible and leads to the discretionary equilibrium with the inherent inflationary bias while they show that a fixed peg of the domestic currency to a foreign currency is credible when the foreign policy maker is precommited. In addition to being ad hoc, this way

[5] See for instance Currie et al. (1992).

[6] Compare for example Begg and Wyplosz (1992) or Eichengreen (1993).

[7] See Eichengreen and Wyplosz (1993) or Svensson (1994) for a more detailed discussion.

[8] Note that it might be questioned whether a policy maker who sticks to his promises given to other countries' policy makers but cheats his private sector will be considered as being credible by other policy makers.

[9] Examples are Horn and Persson (1988) and de Kock and Grilli (1993).

of proceeding is logically inconsistent, because within the standard monetary policy game, pegging the nominal exchange rate and thereby importing the foreign inflation rate is analytically equivalent to targeting the foreign inflation rate. Moreover nominal exchange rate pegging should in general be even welfare *inferior* to inflation targeting in this context, because the latter option allows one to choose the domestically optimal inflation rate instead of just importing the foreign inflation rate. To clarify these issues, the focus of this paper lies in addressing the question: Why may exchange rate targets be more credible than inflation targets?[10]

Three aspects of this question appear to be of particular importance. First the nominal exchange rate is the price of the foreign currency in terms of the domestic currency as determined in the (single) foreign exchange market. In contrast the inflation rate is an artifact derived from many markets, which relies on the use of price indices and may be prone to measurement errors. Secondly, the nominal exchange rate is continuously observable whereas the inflation rate is observed discretely (at best monthly) and with a lag.[11] Finally, a chosen value for the nominal exchange rate target that is consistent with the economic fundamentals can in principle be perfectly achieved when the pegging country completely gives up control over its money supply. Of course, it must also have sufficient international reserves or perfect access to the international credit markets, implying that it can defend its exchange rate target whenever necessary.[12] On the contrary, an inflation target is in reality not perfectly achievable due to uncontrollable factors influencing the money supply, to the instability of money demand, and to the uncertain time lag with which changes in base money are transmitted to inflation changes.[13]

[10] The importance of this question is widely recognized in the literature. Compare, for example, Begg and Wyplosz (1987), Giavazzi and Giovannini (1989), Blackburn and Sola (1993), and Edwards (1993).

[11] Within a closed economy setting, the consequences of this lag on reputation were considered in Grossman and Van Huyck (1986) and Miller and Salmon (1989).

[12] Problems related to potential speculative attacks on the pegged exchange rate regime are therefore assumed away. For a recent review of the literature on speculative attacks see Blackburn and Sola (1993).

[13] Note that the nominal exchange rates of the stable EMS currencies were allowed to fluctuate within ±2.5% bands around the central parity. Since the deviations of actual inflation from the targeted values are by far larger in reality, this is not at odds with the admittedly idealized assumption of the perfect exchange rate controllability. As an example, take the German Bundesbank in the 1980s: It announced corridors for its monetary targets with differences of at least two percent between the lower bound, B^l, and the upper bound, B^u. Provided that the target value was the average between B^l and B^u, the most precise target was announced in 1984 with $B^l = 4\%$ and $B^u = 6\%$. Consequently, this announcement

While these differences indicate potential advantages of nominal exchange rate targeting, the last is of particular importance and shall be elaborated on in the following analysis. To work with the simplest framework possible, it is assumed that the inflation rate is subject to unexpected, exogenous stochastic disturbances, which may for example be thought of as velocity shocks to money demand. Consequently the domestic authority can only incompletely achieve its inflation target. Following Canzoneri (1985), it is then argued that since the authority's inflation target is its private information, individuals do not know with certainty whether ex post deviations from their expected inflation rate are due to unexpected disturbances or due to cheating on part of the authority, which presumably benefits from inflation surprises. Large velocity shocks therefore lead to a loss of the policy maker's reputation and to an inflationary bias, although it is optimal not to renege in a reputational equilibrium.[14]

It is shown below that this inflationary bias from *asymmetric* information can be eliminated when the nominal exchange rate is targeted, given that the exchange rate target is in principle perfectly achievable. In particular, unexpected velocity shocks lead to offsetting changes in international reserves while the nominal exchange rate remains unchanged. Consequently, even under *asymmetric* information, there is no uncertainty about whether the policy maker has reneged on a preannounced pegged nominal exchange rate and a loss of reputation only results when he actually does so.[15]

The plan for the rest of the paper is as follows: In section 2, the basic model and the optimal tax problem are described. Section 3 discusses the outcome of the monetary policy game between the authority and the private sector when the inflation rate is targeted and the nominal exchange rate floats. In particular, in the subsections 3.1 and 3.2, the time consistent solutions under precommitment and discretion are derived. Moreover, the possible realization of the precommitment solution as a reputational equilibrium is discussed under symmetric and asymmetric information. In section 4, the welfare gains from exchange rate targeting under *asymmetric* information are studied and section

corresponded to a $\pm 20\%$ potential deviation of the actual realization from the target. It may be noted that the Bundesbank even missed its target corridors frequently in the 1980s [Compare the annual reports of the Bundesbank].

[14] As Canzoneri (1985) argued, publishing the inflation target would not solve the problem, since the authority had an incentive to misrepresent it.

[15] The crucial role of asymmetric information in explaining the difference between exchange rate and inflation targets has already been noticed by Giavazzi and Giovannini (1989, p. 103), who, however, did not present a formal model.

5 offers some conclusions.

2 The Model

In this section the open economy optimal tax model of de Kock and Grilli (1993) is modified so as to highlight the role of *asymmetric* information about stochastic disturbances affecting the inflation rate. We consider a world of two open economies, referred to as the domestic and the foreign country. In both of them a homogeneous output good is exogenously given and prices are perfectly flexible. The domestic and the foreign output good are supposed to be perfect substitutes and it is assumed that there are no barriers to trade. Hence purchasing power parity holds:

$$e_t = \frac{P_t}{P_t^*}. \tag{1}$$

In equation (1), e_t denotes the nominal exchange rate from the perspective of the domestic country, i.e. the price of foreign currency in terms of domestic currency and P_t is the domestic price level. A star indicates a foreign variable. As a consequence of purchasing power parity, the rate of nominal exchange rate depreciation equals the difference between the domestic and the foreign inflation rate, Π_t and Π_t^*,

$$\hat{e}_t = \frac{\Delta e_t}{e_{t-1}} = \Pi_t - \Pi_t^*, \tag{2}$$

where $\Pi_t^{(*)} := \Delta P_t^{(*)} / P_{t-1}^{(*)}$.

The only difference between the domestic and the foreign country in our model is that the foreign country is assumed to have established a completely independent central bank, whose constitutional goal is price stability. This extreme form of Rogoff's (1985) conservative central banker implies the possibility to precommit and hence the absence of a time consistency problem in the foreign country [Neumann (1991)].[16] In contrast to the foreign central banker,

[16] Compare Walsh (1993) for recent review of the role of central bank independence. Of course, even the "almost independent" central banks in the real world do not usually satisfy all of the necessary and sufficient criteria for complete central bank independence. The German Bundesbank, for instance, has no exchange rate sovereignty, which is rather given to the minister of finance. von Hagen (1989) explores the impact of the resulting exchange

the domestic monetary authority is assumed to be completely dependent on the government.[17] Consequently Rogoff's (1985) suggestion of employing a conservative domestic central banker is not applicable, because the central banker's decisions will merely reflect the preferences of the government. Note that the asymmetry resulting from the different institutional status of the domestic and the foreign central bank may well be a good approximation of the reality of the EMS, at least after 1987.[18]

Domestic inflation policy is described by a highly stylized public finance model of optimal taxation. The domestic authority needs to raise revenues to finance the present value of an exogenously given, known stream of expenditure and to repay the debt inherited from the last period's government. Revenues can be collected through both, output taxation and seigniorage, that is, the proceeds from the creation of money. In addition, the policy maker may also issue bonds to shift expenditure between periods. For simplicity, these bonds are taken to be indexed to ex post inflation. If $\mathcal{G}$ denotes the present value in period 0 of the sum of all future government expenditure relative to GNP, τ_t the average output tax rate in period t, s_t seigniorage relative to GNP in period t, and r the constant and exogenous real interest rate, the government budget constraint in real values may be expressed as:

$$\mathcal{G} = \sum_{t=0}^{\infty} \frac{1}{(1+r)^t}(\tau_t + s_t). \tag{3}$$

Reflecting common practice in the real world, output taxes are assumed to be collected with a one period lag. More precisely, in period $t+1$, the government is supposed to collect tax receipts of $(1+r)\tau_t$ so that the period t value of that period's tax proceeds relative to GNP is τ_t. Note that since we have assumed output taxes to be fully indexed to inflation, any sort of Olivera–Tanzi–effect is absent. The reason for incorporating the collection lag here is rather a technical one as will become apparent in 3.3.3 below.

rate constraints on German monetary policy in the 1980s and finds evidence that, at least ex post, an inflationary bias resulted. In a more realistic setting than the one described here, it would therefore only be assumed that the degree of foreign central bank independence is higher than in the domestic country. However, all arguments would remain the same.

[17] We synonymously refer to the entity of them as the authority or the policy maker.

[18] Essentially, the Bundesbank appears to have aimed for price stability while the other EMS members took the German inflation rate as given and defended their exchange rate parities. Compare Giavazzi and Giovannini (1987), Biltoft and Boersch (1992), and Herz and Röger (1992) for some empirical evidence.

Since all public debt is indexed to ex–post inflation, seigniorage can only be collected from the devaluation of nominal balances as a consequence of anticipated and surprise inflation. To specify the seigniorage revenues, individuals are supposed to be forward looking, to have rational expectations, and a demand for nominal balances that depends negatively on the expected inflation rate. Following de Kock and Grilli (1993), we may then represent seigniorage by a first order approximation,

$$s_t = \alpha(\Pi_t - \Pi_t^e) + \alpha\beta\Pi_t^e, \tag{4}$$

where Π_t^e is the inflation expectation of individuals at the end of period $t-1$, i.e. $\Pi_t^e = E_{t-1}(\Pi_t)$. The constants α and β are assumed to be positive, because an increase of either expected or unexpected inflation is supposed to generate additional seigniorage.[19] In addition, β is supposed to be smaller than one, because the demand for nominal balances is assumed to be elastic with respect to expected inflation, reflecting that private agents will reduce their nominal balances when they expect higher inflation rates. In contrast, unexpected inflation is a revenue instrument with an inelastic revenue tax base and thus results in higher marginal revenues than expected inflation.

The substitution of (4) into (3) yields an intertemporal budget constraint in terms of the tax rate and the inflation rate:

$$\mathcal{G} = \sum_{t=0}^{\infty} \frac{1}{(1+r)^t}\Big[\tau_t + \alpha(\Pi_t - \Pi_t^e) + \alpha\beta\Pi_t^e\Big]. \tag{5}$$

Both output taxation and inflation are assumed to result in social loss. The social loss from output taxation occurs as a consequence of, amongst others, collection costs while the social loss from inflation comes from suboptimal holdings of nominal balances (due to expected inflation) and from menu costs (due to expected and unexpected inflation), which arise from the administrative costs of posting new prices and of adjusting the tax system to be fully indexed to inflation.[20] As is standard, we use an additively separable and quadratic representation of the social loss L_t in any period t. The present discounted

[19] We implicitly assume that the optimal inflation rate lies on the left side of the seigniorage Laffer curve. This would result endogenously in a more general model in which seigniorage depends concavely on inflation; see Herrendorf (1994c), where I also discuss in more detail the seigniorage collected from the devaluation of nominal government debt through inflation surprises.

[20] For a further discussion, compare Driffill, Mizon and Ulph (1990).

value of current and future period–by–period social loss then is:

$$L = \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} L_t = \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} \left(\tau_t^2 + c\Pi_t^2\right), \tag{6}$$

where δ denotes the policy maker's discount rate and c is the weight attached to the losses from inflation relative to the losses from output taxation. We will also need to impose a condition of the form

$$(1+\delta) < (1+r)^2 \tag{7}$$

on the discount rate. The reason for (7) will become obvious later when the optimal policy is determined.

Since we want to study the role of asymmetric information, we introduce uncertainty by assuming that the inflation rate Π_t is only controllable up to a stochastic disturbance ϵ_t. This may, for instance, be justified by aggregation problems, measurement errors, money supply shocks, or velocity shocks.[21] If π_t denotes the inflation target of the policy maker, we may thus express the actual inflation rate as the sum of his inflation target and a disturbance ϵ_t, which is supposed to have zero mean and a finite variance σ_ϵ^2,[22]

$$\Pi_t = \pi_t + \epsilon_t. \tag{8}$$

Two different scenarios are to be distinguished now: The *symmetric* information case, in which both, the private sector and the policy maker know the realizations of the disturbance ex post, and the *asymmetric* information case, in which the realizations of the disturbance are only known to the policy maker ex post. The policy maker can compute the realization of ϵ_t in either case because he always knows his target π_t. The private sector, on the contrary, can only figure out the realization of the disturbance in the *symmetric* information case, in which it knows the policy maker's inflation target. In contrast, in the *asymmetric* information case, the target is the authority's private information and the private sector is supposed to know only the distribution of the

[21] See Herrendorf (1994b) for a set–up that explicitly accounts for these effects. Similar assumptions were also made by Basar and Salmon (1990), Canzoneri (1985), or Cukierman and Meltzer (1986a,b).

[22] Note that this reduced form for inflation could be justified by explicitly modeling the money market equilibrium as in Canzoneri (1985), which, however, would not add much insight to the present set–up.

disturbance.

Independent of the information assumptions, the domestic authority's optimal taxation problem is to find a sequence of tax rates $\{\tau_t\}$ and inflation targets $\{\pi_t\}$ that minimizes the expected social loss (6) subject to the intertemporal budget constraint (5). In order to implement the optimal policy, the authority may directly target domestic inflation while the nominal exchange rate floats freely or it may give up control over the money supply and target the nominal exchange rate so as to achieve indirectly the desired domestic inflation target.[23] Independent of the exchange rate regime, a crucial constraint on the optimal policy is its credibility because if it were not credible, the private sector would expect a different policy and it would not constitute an equilibrium policy. We define a policy plan to be credible when it is *endogenously* time consistent, that is, when it is *ex ante* and *ex post* optimal for the policy maker to follow that plan.[24] In particular, an exchange rate system is called credible if there will be no incentive to renege on the decision to implement it subsequently.

3 The Optimal Tax Problem under Floating Exchange Rates

We first consider the optimal policy when the inflation rate is targeted and the nominal exchange rate floats freely. Purchasing power parity then implies that the nominal exchange rate is entirely determined by the differential between the domestic and the foreign inflation rate [compare (2)]. This scenario is therefore equivalent to the one in a closed economy usually analyzed by the public finance literature on optimal inflation rates.

3.1 The Optimal Policy under Precommitment

When the government is precommited to follow the ex ante optimal decision, the inherent time consistency problem does not arise by definition. Consequently, the solution to the optimal tax problem does not depend on the in-

[23] Compare equation (2).

[24] Compare Kydland and Prescott (1977). By the term endogenously time consistent we intent to exclude the whole variety of time consistent solutions that result from imposing arbitrary restrictions on the optimization problem.

formational scenario. We need to solve the authority's optimization problem in this case, where a precommited policy maker chooses sequences $\{\tau_t^{prec}\}$ and $\{\pi_t^{prec}\}$ so as to minimize the expected value of the social losses (6) subject to the intertemporal budget constraint (5) and to the constraint that the private sector expects whatever tax and inflation sequence is optimal for the precommited policy maker. The first order conditions for optimality are (5) along with

$$\tau_t^{prec} = \left(\frac{1+\delta}{1+r}\right)^t \tau_0^{prec}, \tag{9.a}$$

$$\pi_t^{prec} = \left(\frac{1+\delta}{1+r}\right)^t \pi_0^{prec}, \tag{9.b}$$

$$\pi_t^{prec} = \frac{\alpha\beta}{c}\tau_t^{prec}, \qquad \forall t. \tag{9.c}$$

In the special case in which the discount factor δ equals the real interest rate r, constant tax rates and inflation targets are optimal in our simple set–up, delivering complete revenue smoothing. In general, however, optimal inflation rates and optimal taxes grow (fall) with a constant factor, depending on whether the discount rate is larger (smaller) than the real interest rate. This corresponds to the intuition that a policy maker with $\delta > r$ optimally collects more revenues in the future because the future loss is less important to him today. Moreover, in line with the Ramsey–principle, the optimal inflation rate target in any period is larger, the larger is the marginal revenue from inflation, $\alpha\beta$, relative to its marginal losses c.[25]

In order to find an explicit expression for π_0^{prec}, we combine the government budget constraint and the first order conditions:

$$\pi_0^{prec} = \frac{\left[(1+r)^2 - (1+\delta)\right]\alpha\beta}{(1+r)^2\left[c + (\alpha\beta)^2\right]}\mathcal{G}. \tag{10}$$

Note that (9.c) and (10) also imply an optimal value for τ_0^{prec}. Putting this expression and the first order conditions into the expression for expected social loss, (6), and taking expectations, we get the expected present value of social

[25] The corresponding ratio for τ does not appear in (9.c) since it is equal to a constant that cancels.

loss under precommitment:[26]

$$E_0^{sym}\Big(L^{prec}\Big) = \frac{\Big[(1+r)^2-(1+\delta)\Big]c}{(1+r)^2\Big[c+(\alpha\beta)^2\Big]}\Big(\mathcal{G}\Big)^2 + c\left(\frac{1+\delta}{\delta}\right)\sigma_\epsilon^2. \qquad (11)$$

The last term in this expression reflects the loss arising from the variability of the realized inflation rate around the target inflation rate due to the stochastic disturbances ϵ_t.

3.2 The Optimal Policy under Discretion

Since the pioneering work of Kydland and Prescott (1977) and Calvo (1978), it is well known in the literature that the ex ante optimal policy is time inconsistent when the authority is not precommited, but has discretion over the policy instruments.[27] In our set–up, this is easy to see; since $\beta < 1$, an unexpected marginal increase of the target inflation rate above the precommitment target generates higher marginal revenues than an expected marginal increase while the marginal social losses are the same. Since optimality requires that the marginal revenue from *expected* inflation under precommitment be equal to the marginal losses, the optimal tax mix under precommitment exhibits higher marginal revenues from an *unexpected* increase of the inflation target than marginal losses. The precommitment solution is thus time inconsistent under discretion.

Of course, rational forward looking individuals realize the potential for time inconsistency and thus do not base their decisions on inflation expectations given by $\{\pi_t^{prec}\}$ when the authority has discretion. In a time consistent equilibrium, they will instead expect a target inflation rate for which the marginal revenue from a surprise equals the marginal loss. As a consequence, the policy maker has to take this expected inflation rate of the private sector as given when optimizing. Note that again it does not play an instrumental role whether we are in the symmetric or asymmetric informational scenario; the reason here is that the private sector simply chooses its expectations to ensure that the policy maker has no incentive to create inflation surprises regardless of the asymmetry of information.

[26] Note that the existence of the infinite sums is ensured through condition (7).

[27] See also Barro and Gordon (1983a, 1983b).

The optimal tax problem under discretion is to choose $\{\tau_t^{disc}\}$ and $\{\pi_t^{disc}\}$ so as to minimize the expected value of social loss, (6), subject to the intertemporal budget constraint, (5), as well as to a sequence $\{(\pi_t^{disc})^e\}$ of given inflation expectations of the private sector. Along with (5), the first order conditions are now:

$$\tau_t^{disc} = \left(\frac{1+\delta}{1+r}\right)^t \tau_0^{disc}, \tag{12.a}$$

$$\pi_t^{disc} = \left(\frac{1+\delta}{1+r}\right)^t \pi_0^{disc}, \tag{12.b}$$

$$\pi_t^{disc} = \frac{\alpha}{c}\tau_t^{disc}, \qquad \forall t. \tag{12.c}$$

The optimal inflation rate and the expected social loss under discretion can as before be computed from these first order conditions and the intertemporal budget constraint (5):

$$\pi_0^{disc} = \frac{\left[(1+r)^2 - (1+\delta)\right]\alpha}{(1+r)^2(c+\alpha^2\beta)}\mathcal{G}, \tag{13}$$

$$E_0^{sym}\left(L^{disc}\right) = \frac{\left[(1+r)^2 - (1+\delta)\right]c\,(c+\alpha^2)}{(1+r)^2\,(c+\alpha^2\beta)^2}\left(\mathcal{G}\right)^2 + c\left(\frac{1+\delta}{\delta}\right)\sigma_\epsilon^2. \tag{14}$$

Note that it is rational for private agents to expect $\{\pi_t^{disc}\}$, because at any time the marginal revenues MR_t^{dev} from an unexpected increase of the inflation target over π_t^{disc} equal the marginal losses ML_t^{dev} as perceived by the policy maker:[28]

$$MR_t^{dev} = \lambda_t\alpha = 2\alpha\tau_t^{disc} = 2c\pi_t^{disc} = ML_t^{dev}. \tag{15}$$

The policy determined above therefore is a time consistent equilibrium. Recalling that $\beta < 1$, we furthermore observe that the inflation rate under discretion is larger than π_t^{prec} in every period,

$$\pi_t^{prec} < \pi_t^{disc}. \tag{16}$$

The time inconsistency of the precommitment solution hence results in the standard inflationary bias. Intuitively, it is clear that this inflationary bias

[28] λ_t is the Lagrange multiplier of the optimization problem, that is, the marginal social welfare gain of one additional unit of revenues.

causes a loss of expected welfare in the discretionary equilibrium compared to the precommitment solution, because $\{\tau_t^{disc}\}$ and $\{\pi_t^{disc}\}$ were not chosen under precommitment although they were feasible. Formally, this follows immediately from (11) and (14):

$$E_0^{sym}\left(L^{prec}\right) < E_0^{sym}\left(L^{disc}\right). \tag{17}$$

3.3 Reputational Equilibria as a Solution to the Time Consistency Problem

Having realized the welfare inferiority of the time consistent solution under discretion, we now show how reputational equilibria can resolve the time consistency problem. For simplicity we again follow de Kock and Grilli (1993) in that we apply the concept of trigger strategy equilibria.[29]

3.3.1 Reputational Equilibria under Symmetric Information

To have a benchmark case, we need to discuss reputational equilibrium under *symmetric* information when individuals know ex post the realizations of the stochastic disturbance and hence the government's inflation target. Confronted with a trigger strategy of the private sector, the policy maker faces a trade–off between resisting the and giving way to the temptation of deviating from the inflation target that is optimal under precommitment. In order to model this trade–off, we assume that he starts the game with reputation and that in any period t he keeps his reputation when he does not deviate from the pre–announced inflation target. The private sector then expects π_t^{prec} for the next period.

On the contrary, if he reneges and collects the one period gains from an unexpected increase of the inflation target, the authority loses its reputation forever and the private sector expects the discretionary inflation rate for all future periods.[30] Consequently, the economy reverts from the precommitment solution to the discretionary solution. Although the policy maker cannot

[29] See Friedman (1971) for the introduction of trigger strategies into the theory of oligopolies.

[30] Note that finite punishment periods may well be sufficient to construct a reputational equilibrium. They are not considered here, because they would not add much insight but rather complicate the algebra.

precommit, the precommitment solution can be established as a reputational equilibrium as usual in this literature if the expected present value of the social losses from reneging on it is larger than the expected present value of the social gains. Note that if the creation of surprise inflation improves expected social welfare, it is optimal to collect the gains as soon as possible, because the future is discounted. Without loss of generality, we may therefore concentrate on the problem of creating surprise inflation in period zero.

If the authority creates surprise inflation in period zero, the discretionary equilibrium materializes from period one on. This implies that the intertemporal budget constraint (5) must be modified. In particular the revenues from the new optimal inflation sequence $\{\pi_t^{dev}\}$ are equal to $\alpha(\pi_0^{dev} - \pi_0^{prec}) + \alpha\beta\pi_0^{prec}$ in period zero and equal to $\alpha\beta\pi_t^{dev}$ in all subsequent periods. Equation (5) therefore changes to:

$$\mathcal{G} = \left[\tau_0^{dev} + \alpha\left(\pi_0^{dev} - \pi_0^{prec}\right) + \alpha\beta\pi_0^{prec}\right] + \sum_{t=1}^{\infty} \frac{1}{(1+r)^t}\left[\tau_t^{dev} + \alpha\left(\pi_t^{dev} - (\pi_t^{dev})^e\right) + \alpha\beta(\pi_t^{dev})^e\right], \qquad (18)$$

where the given inflation expectation satisfies:

$$(\pi_t^{dev})^e = \pi_t^{dev} \qquad \forall t \geq 1. \qquad (19)$$

Note that we have implicitly assumed that the period–zero–taxes are also reoptimized after an inflation surprise, although it certainly takes more time in the real world to change taxes unexpectedly than inflation. However, since output taxes are collected with a one period lag, the policy maker may well be able to change the tax rate of period zero.

The sequence of tax and inflation rates, $\{\tau_t^{dev}\}$ and $\{\pi_t^{dev}\}$, that minimizes expected social loss (6) subject to the modified intertemporal budget constraint (18) and the modified sequence $(\pi_0^{prec})^e, (\pi_1^{disc})^e, (\pi_2^{disc})^e, \ldots$ of inflation expectations is characterized by (18) along with the additional first order conditions:

$$\tau_t^{dev} = \left(\frac{1+\delta}{1+r}\right)^t \tau_0^{dev}, \qquad (20.a)$$

$$\pi_t^{dev} = \left(\frac{1+\delta}{1+r}\right)^t \pi_0^{dev}, \qquad (20.b)$$

$$\pi_t^{dev} = \frac{\alpha}{c}\tau_t^{dev}, \qquad \forall t. \tag{20.c}$$

It should be stressed that although these first order conditions may at first sight appear to be the same as under discretion, the intertemporal budget constraint (18) is different from (5), leading to different optimal tax and inflation sequences. For a reputational equilibrium to exist, the expected social loss after a deviation from the precommitment solution, $E_0^{sym}(L^{dev})$, must not be smaller than the expected social loss without a deviation, $E_0^{sym}(L^{rep})$. Realizing that under symmetric information $E_0^{sym}(L^{rep}) = E_0^{sym}(L^{prec})$, the condition for the existence of a reputational equilibrium may be written as:

$$E_0^{sym}\left(L^{prec}\right) \leq E_0^{sym}\left(L^{dev}\right). \tag{21}$$

It is not straightforward to solve this condition explicitly.[31] However, it can be shown that there are parameter values for which a reputational equilibrium exists, while it does not for others. Appendix A contains the technical details of this argument as well as the explicit characterization of the optimal surprise inflation rate and the expected social loss after a surprise, given the policy maker reneges. Notice that for the present purpose it is sufficient to know that an equilibrium under *symmetric* information sometimes does and sometimes does not exit, because we are mainly interested in understanding the differences between the equilibria under *symmetric* and under *asymmetric* information rather than the equilibrium under *symmetric* information itself.

3.3.2 Reputational Equilibria under Asymmetric Information

In contrast to the precommitment and the discretionary paradigm, the existence and the properties of a reputational equilibrium are affected by *asymmetric* information. This comes about because private agents cannot tell with certainty anymore whether the authority has deliberately deviated from the precommitment solution or whether the deviation of Π_t from π_0^{prec} is due to an unexpected disturbance. As Canzoneri (1985) argued, publishing private

[31] The problem appears to be that we deal with a dynamic because government bonds are present in our model. In contrast, de Kock and Grilli (1993) can solve their equilibrium condition since they exclude bonds from the analysis by assumption, implying that there is no intertemporal tax smoothing anymore and consequently that their game is repeated in nature. Since this is certainly unsatisfactory within an optimal taxation context, bonds are considered here.

information would not solve this problem, because the policy maker had an incentive to misrepresent its inflation target in order to hide reneging on the precommitment solution. However, it may still be possible to establish the precommitment solution as a reputational equilibrium under discretion. Following Canzoneri (1985), the private sector may choose a trigger value $\mathcal{T}$ and revert to the discretionary equilibrium if the difference between Π_t and π_t becomes larger than $\mathcal{T}$. In order to derive an existence condition of a reputational equilibrium for any given $\mathcal{T}$, we need to determine the expected social losses depending on whether the authority creates surprise inflation or not. We will then discuss how the optimal $\mathcal{T}$ is chosen. As before, we restrict the analysis to the creation of surprise inflation in period zero.

1. The optimal policy when no inflation surprise is created in period zero:

The probability $p^{rep}(\mathcal{T})$ that the policy maker loses his reputation in any period t conditional on that the economy was in the reputational equilibrium in period $t-1$ equals the probability that $\Pi_t - \pi_t > \mathcal{T}$. Since $\Pi_t - \pi_t = \epsilon_t$ and ϵ_t is i.i.d., we may express $p^{rep}(\mathcal{T})$ as:

$$p^{rep}(\mathcal{T}) = \int_{\mathcal{T}}^{\infty} f(\epsilon_0)d\epsilon_0, \tag{22}$$

where $f(.)$ denotes the density of ϵ. It is important to realize that if the authority has not reneged, but $\Pi_t - \pi_t > \mathcal{T}$, it will not lose its reputation forever. This comes about because no additional revenues have been collected through surprise inflation, implying that *all* future optimal tax and inflation rates remain unchanged. In contrast, if surprise inflation were created, additional revenues would be collected that could not be hoarded ad infinitum. To keep matters as simple as possible, the creation of an inflation surprise is assumed to become obvious when the tax proceeds are collected in the next period.[32] Consequently, the discretionary outcome will materialize for only one period when the policy maker loses his reputation erroneously.

The probability $p_t(\mathcal{T})$ that the economy erroneously is in the discretionary equilibrium in period t equals the probability with which the policy

[32] We may justify this assumption by the fact that most real world central banks are required to annually publish their balance sheet, which has to be approved by an independent accountant.

maker loses his reputation in period $t-1$ conditional on the fact that he had full reputation in that period:

$$p_0(\mathcal{T}) = 0, \quad p_t(\mathcal{T}) = p^{rep}(\mathcal{T})\Big[1 - p_{t-1}(\mathcal{T})\Big] \quad (t = 1, 2, \dots\ ). \tag{23}$$

Similarly, the probability that the precommitment solution is the outcome in period t is equal to the probability of the discretionary outcome in the last period, $p_{t-1}(\mathcal{T})$, plus the probability that the policy maker has reputation in period t conditional on that he had reputation in the period before:

$$\Big[1 - p_t(\mathcal{T})\Big] = p_{t-1}(\mathcal{T}) + \Big[1 - p^{rep}(\mathcal{T})\Big]\Big[1 - p_{t-1}(\mathcal{T})\Big]. \tag{24}$$

Under *asymmetric* information, the expected social loss when the authority never reneges can therefore be expressed as:[33]

$$\begin{aligned} E_0^{asym}\Big(L^{rep}(\mathcal{T})\Big) = \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} \Big[\Big(1 - p_t(\mathcal{T})\Big) E_0^{sym}\Big(L_t^{prec}\Big) \\ + p_t(\mathcal{T}) E_0^{sym}\Big(L_t^{disc}\Big)\Big], \end{aligned} \tag{25}$$

where L_t^{prec} and L_t^{disc} denote the expected period t social losses under precommitment and under discretion in period t. Note that (25) can be rewritten to

$$\begin{aligned} E_0^{asym}\Big(L^{rep}(\mathcal{T})\Big) &= E_0^{sym}\Big(L^{disc}\Big) - \sum_{t=0}^{\infty} \frac{1 - p_t(\mathcal{T})}{(1+\delta)^t} E_0^{sym}\Big(L_t^{disc} - L_t^{prec}\Big) \\ &= E_0^{sym}\Big(L^{prec}\Big) + \sum_{t=0}^{\infty} \frac{p_t(\mathcal{T})}{(1+\delta)^t} E_0^{sym}\Big(L_t^{disc} - L_t^{prec}\Big). \end{aligned} \tag{26}$$

Hence, when a reputational equilibrium under *asymmetric* information exists it will have poorer welfare properties than a reputational equilibrium under *symmetric* information. However, it still welfare–dominates the discretionary equilibrium:

$$\begin{aligned} E_0^{sym}\Big(L^{rep}\Big) &= E_0^{sym}\Big(L^{prec}\Big) \\ &< E_0^{asym}\Big(L^{rep}(\mathcal{T})\Big) \end{aligned}$$

[33] The infinite sums in the following expressions exist because $p_t(\mathcal{T})$ and $(1 - p_t(\mathcal{T}))$ are smaller than one and because $\sum_{t=0}^{\infty} 1/(1+\delta)^t E_0^{sym}(L_t^{prec})$ and $\sum_{t=0}^{\infty} 1/(1+\delta)^t E_0^{sym}(L_t^{disc})$ exist.

$$< E_0^{sym}\left(L^{disc}\right) = E_0^{asym}\left(L^{disc}\right). \tag{27}$$

The expected welfare loss from *asymmetric* information when a reputational equilibrium exists reflects the inflationary bias, arising because, even though it is optimal for the policy maker not to create surprise inflation, the economy reverts to the discretionary equilibrium with a positive probability in any period.

2. The optimal policy after surprise inflation has been created in period zero:

To derive the probabilities with which the policy maker loses its reputation after an inflation surprise in period zero, we recall that he certainly loses reputation in period one when the tax proceeds of period zero are collected. This implies that with probability one the discretionary outcome materializes from period two onwards. In contrast, the outcome in period one depends on the realization of the ϵ_0–disturbance. On the one hand, if $\epsilon_0 + (\pi_0^{dev} - \pi_0^{prec}) > \mathcal{T}$, the private sector spots the inflation surprise already in period zero and the discretionary outcome materializes in period one. This happens with probability

$$p^{dev}(\mathcal{T}) = \int_{[\mathcal{T}-(\pi_0^{dev}-\pi_0^{prec})]}^{\infty} f(\epsilon_0) d\epsilon_0. \tag{28}$$

On the other hand, if $\epsilon_0 + (\pi_0^{dev} - \pi_0^{prec}) \leq \mathcal{T}$, the policy maker will still have reputation in period one despite the fact that he has reneged in period zero. The probability of this alternative is $(1 - p^{dev}(\mathcal{T}))$. The optimal tax and inflation sequences in these two cases are characterized in an Appendix B. As before they may be expressed as functions of the rate of surprise inflation in period zero, π_0^{dev}. Consequently, the expected social losses may also be expressed as functions of π_0^{dev}:

$$E_0^{asym}\left(L^{dev}(\pi_0^{dev}, \mathcal{T})\middle|\epsilon_0 \leq \mathcal{T} - (\pi^{dev} - \pi^{prec})\right)$$
$$= \left(\bar{\tau}_0(\pi_0^{dev})\right)^2 + c\left(\pi_0^{dev}\right)^2 + \frac{(c+\alpha^2)(1+\delta)}{c\left[(1+r)^2 - (1+\delta)\right]}\left(\bar{\tau}_0(\pi_0^{dev})\right)^2, \tag{29}$$

$$E_0^{asym}\left(L^{dev}(\pi_0^{dev}, \mathcal{T})\middle|\epsilon_0 > \mathcal{T} - (\pi^{dev} - \pi^{prec})\right)$$
$$= \left(\tilde{\tau}_0(\pi_0^{dev})\right)^2 + c\left(\pi_0^{dev}\right)^2 + \frac{(c+\alpha^2)(1+\delta)}{c\left[(1+r)^2 - (1+\delta)\right]}\left(\tilde{\tau}_0(\pi_0^{dev})\right)^2. \tag{30}$$

3. Characterization of the optimal rate of surprise inflation:

Applying (29) and (30), we can now determine the optimal π_0^{dev} under *asymmetric* information. It has to minimize the following version of the present value of expected future social loss:[34]

$$\begin{aligned} & E_0^{asym}\Big(L^{dev}(\pi_0^{dev},\mathcal{T})\Big) \\ &= \Big(1-p^{dev}(\mathcal{T})\Big)E_0^{asym}\Big(L^{dev}(\pi_0^{dev},\mathcal{T})\Big|\epsilon_0 \leq \mathcal{T}-(\pi^{dev}-\pi^{prec})\Big) \\ & +p^{dev}(\mathcal{T})E_0^{asym}\Big(L^{dev}(\pi_0^{dev},\mathcal{T})\Big|\epsilon_0 > \mathcal{T}-(\pi^{dev}-\pi^{prec})\Big). \end{aligned} \tag{31}$$

The optimal π_0^{dev} is characterized by the first order condition:

$$\begin{aligned} & \frac{\partial p^{dev}(\mathcal{T})}{\partial \pi_0^{dev}}\Big[E_0^{asym}\Big(L^{dev}(\pi_0^{dev},\mathcal{T})\Big|\epsilon_0 > \mathcal{T}-(\pi^{dev}-\pi^{prec})\Big) \\ & \qquad -E_0^{asym}\Big(L^{dev}(\pi_0^{dev},\mathcal{T})\Big|\epsilon_0 \leq \mathcal{T}-(\pi^{dev}-\pi^{prec})\Big)\Big] \\ &= -\Big(1-p^{dev}(\mathcal{T})\Big)\frac{\partial}{\partial \pi_0^{dev}}E_0^{asym}\Big(L^{dev}(\pi_0^{dev},\mathcal{T})\Big|\epsilon_0 \leq \mathcal{T}-(\pi^{dev}-\pi^{prec})\Big) \\ & \quad -p^{dev}(\mathcal{T})\frac{\partial}{\partial \pi_0^{dev}}E_0^{asym}\Big(L^{dev}(\pi_0^{dev})\Big|\epsilon_0 > \mathcal{T}-(\pi^{dev}-\pi^{prec})\Big). \end{aligned} \tag{32}$$

Provided that the policy maker reneges under *asymmetric* information, optimality requires the surprise inflation rate to equate the marginal expected increase of social loss from a marginal increase of surprise inflation [lhs of (32)] with the marginal expected decrease of social loss [rhs of (32)]. More precisely, the marginal expected increase of social loss is equal to the marginal increase of the probability that the economy reverts to the discretionary equilibrium, $\partial p^{dev}(\mathcal{T})/\partial \pi_0^{dev}$, times the resulting expected social loss; the marginal social gain from an unexpected increase of inflation equals the resulting expected reduction of social loss if $p^{dev}(\mathcal{T})$ remained unchanged.

Although we have not explicitly characterized the optimal deviation rate under *asymmetric* information, we can compare the expected social losses after surprise inflation under *symmetric* and under *asymmetric* information. To do this, imagine which expected social loss would arise under *asymmetric* informa-

[34] Notice that since we actually determine the optimal rate of surprise inflation, sticking to the precommitment solution will be a *global* optimum provided a reputational equilibrium exists. In contrast, Canzoneri (1985) only discussed marginal inflation surprises. Consequently, his reputational solution may only be a *local* expected welfare optimum.

tion if the tax and inflation policy optimal under *symmetric* information was implemented. Since with a positive probability, the collected revenues from inflation for this policy are larger under *asymmetric* than under *symmetric* information, there would also be a positive probability of tax and inflation cuts. Under *asymmetric* information, the expected social loss from this policy would thus be smaller than the expected loss from the same policy under *symmetric* information. Since the policy optimal under *symmetric* information is in general not the optimal one under *asymmetric* information, we conclude that

$$E_0^{asym}\Big(L^{dev}(\mathcal{T})\Big) < E_0^{sym}\Big(L^{dev}\Big). \tag{33}$$

4. The relation between the equilibrium conditions under symmetric and asymmetric information:

A reputational equilibrium under *asymmetric* information now exists, if there exists a trigger value $\mathcal{T}$ such that the expected social loss after an inflation surprise in period zero is not smaller than the expected social loss without surprise inflation:

$$E_0^{asym}\Big(L^{rep}\Big) \leq E_0^{asym}\Big(L^{dev}(\mathcal{T})\Big). \tag{34}$$

Since the left hand side of this condition is increasing in $\mathcal{T}$, the minimal trigger value for which (34) is fulfilled will guarantee the existence of a reputational equilibrium while minimizing the inflationary bias from *asymmetric* information. In order to study the relation between the existence conditions of a reputational equilibrium under *symmetric* and under *asymmetric* information, we observe that (27) together with (33) implies

$$E_0^{asym}\Big(L^{dev} - L^{rep}\Big) < E_0^{sym}\Big(L^{dev} - L^{rep}\Big). \tag{35}$$

Since for a reputational equilibrium to exist the expected difference $L^{dev} - L^{rep}$ must not be negative, the existence of a reputational equilibrium under *asymmetric* information implies the existence under *symmetric* information, but not vice versa. Moreover, as has been shown in the previous section, a reputational equilibrium under *symmetric* information does not always exist. From inequality (35) and the continuity of the expected social loss functions, it therefore follows that there must exist parameter constellations, for which a reputational equilibrium only exists under *symmetric* information. Summarizing, there are three possible cases to be considered:

1. A reputational equilibrium exists under both *symmetric* and *asymmetric* information.

2. A reputational equilibrium exists under *symmetric* but not under *asymmetric* infomation.

3. A reputational equilibrium does not exit under either *symmetric* or under *asymmetric* information.

The previous results allow us to express explicitly the expected loss of social welfare as a consequence of the inflationary bias from *asymmetric* information in all of these cases. In case 1., the expected social loss equals:

$$E_0^{asym}\left(L^{rep}\right) - E_0^{sym}\left(L^{rep}\right) = \sum_{t=0}^{\infty} \frac{p_t}{(1+\delta)^t} E_0^{sym}\left(L_t^{disc} - L_t^{prec}\right) > 0. \quad (36)$$

Moreover, in case 2., the expected welfare loss resulting from *asymmetric* information is even larger, amounting to $E_0^{sym}(L^{disc} - L^{prec})$. Finally and trivially, in case 3., no expected loss of social welfare results from *asymmetric* information.

In the following section, we will discuss under what circumstances the welfare loss due to *asymmetric* information can be eliminated through the implementation of a pegged nominal exchange rate system.

4 The Optimal Tax Problem under Pegged Exchange Rates

When the authority implements an exchange rate peg, it must give up control over the domestic money supply. Purchasing power parity then implies that the domestic inflation rate is endogenously determined by the rate of nominal exchange rate depreciation $\hat{e}_t$ and the foreign inflation rate Π_t^*.[35] In the special case of an exchange rate peg, the rate of nominal exchange rate depreciation is zero and the domestic inflation rate is equal to the foreign one. As in (8), the foreign inflation rate is assumed to be equal to the sum of the foreign inflation target π_t^* and a foreign i.i.d. disturbance ϵ_t^*:

$$\Pi_t^* = \pi_t^* + \epsilon_t^*. \quad (37)$$

[35] Compare equation (2).

Moreover, ϵ_t^* is again supposed to have zero mean and a finite variance σ_ϵ^{*2}. Substituting expression (37) into (2), we find:

$$\Pi_t = (\pi_t^* + \epsilon_t^*) + \hat{e}_t. \tag{38}$$

If the crawling peg is credible, equation (38) implies that the rational inflation expectation of the private sector is equal to the (credible) foreign inflation target plus the rate of nominal exchange rate depreciation:[36]

$$\Pi_t^e = \pi_t^* + \hat{e}_t. \tag{39}$$

For any given foreign inflation rate target, there thus exists a unique rate of nominal exchange rate depreciation, $\hat{e}_t(\pi_t, \pi_t^*) = \pi_t - \pi_t^*$, which yields the desired domestic inflation rate target π_t in expected terms.

4.1 Exchange Rate Pegging under Symmetric Information

Under symmetric information, the only difference between implementing the crawling peg $\{\hat{e}_t(\pi_t, \pi_t^*)\}$ and targeting the equivalent inflation rate $\{\pi_t\}$ is the precision with which the target can be achieved. Independently of whether the economy is in the precommitment, the discretionary, or the reputational equilibrium, the difference between the expected social loss under inflation targeting compared to the crawling peg $\{\hat{e}_t\}$ is equal to:

$$E_0^{sym}\Big(L(\text{inf. targ.}) - L(\text{craw. peg})\Big) = \left(\frac{1+\delta}{\delta}\right)\left(\sigma_\epsilon^2 - \sigma_{\epsilon^*}^2\right). \tag{40}$$

Equation (40) shows that the properly designed crawling peg improves expected social welfare under *symmetric* information, if the foreign inflation rate can be controlled more precisely than the domestic one, which may not be an implausible situation. The reason lies in the fact that on the one hand the optimal foreign inflation rate is presumably lower than the domestic one if the foreign central bank is independent and aims for price stability while the dependent domestic central bank determines inflation according to the previous optimal taxation considerations.[37] On the other hand, the variance of inflation

[36] Recall that the foreign inflation target was assumed to be credible because of the independence of foreign central bank. The expectation of this target is thus equal to the target.

[37] Compare (10). If the relative social loss of inflation c is not "much larger than one", significantly positive inflation rates are optimal from a domestic public finance point of view.

may well be related positively to the level of inflation.[38]

It should be stressed that if the domestic authority could control the inflation rate as precisely as the foreign one, then implementing $\{\hat{e}_t(\pi_t, \pi_t^*)\}$ would be completely equivalent to targeting π_t under *symmetric* information. Moreover, an exchange rate peg with a fixed parity $[\hat{e}_t = 0]$ would then decrease expected social welfare, because it would result in the foreign inflation rate instead of the domestically optimal inflation rate. In particular, this would hold true in the absence of uncertainty when both, the domestic and the foreign country can precisely control their inflation rates. This result indicates the problem with the monetary policy game literature on exchange pegs as disinflation devices, which was addressed above: within the standard, highly stylized models without uncertainty, it is logically inconsistent to assume welfare gains from exchange rate pegging compared to inflation targeting. [39] We now argue that this inconsistency may be removed through the introduction of *asymmetric* information. To show this, we concentrate on situations in which the precommitment solution can be implemented as a reputational equilibrium under *symmetric* information; otherwise there is no difference between the *symmetric* and the *asymmetric* information scenario.

4.2 Credible Purchases of Credibility under Asymmetric Information

4.2.1 A Crawling Peg

Since we have restricted attention to the case in which the foreign country does not experience an inflationary bias at all, the crawling peg $\{\hat{e}_t(\pi_t, \pi_t^*)\}$ achieves the domestic inflation target $\{\pi_t\}$ in expected terms. Deviations from the target that are not caused by verifiable foreign shocks are thus only possible if the domestic policy maker creates surprise inflation. Consequently, the situation is identical to inflation targeting under *symmetric* information and the policy

This appears to have been the relevant case for the participants of the EMS that experienced a major disinflation process. Higher collection cost of output and excise taxes are usually taken as the reason for a low weight of the social losses from inflation in the expected social loss function; compare Canzoneri and Rogers (1990). The same argument certainly applies to many other inflation prone countries.

[38] See Taylor (1983) for empirical evidence and Cukierman and Meltzer (1986b) for a theoretical justification.

[39] This problem occurs, for example, in the models of Currie et al. (1992) and de Kock and Grilli (1993).

maker only loses his reputation if he actually deviates from the targeted nominal exchange rate. In particular, the domestic precommitment outcome $\{\pi_t^{prec}\}$ can be implemented through the crawling peg $\{\hat{e}_t(\pi_t^{prec}, \pi_t^*)\}$ as a reputational equilibrium under *asymmetric* information whenever it can be implemented as a reputational equilibrium through inflation targeting under *symmetric* information. The implementation of a crawling peg then is endogenously time consistent and credible. Note that this is true despite the fact that there are parameter constellations in which targeting $\{\pi_t^{prec}\}$ under *asymmetric* information is not credible. This is the sense in which the domestic authority can "credibly purchase credibility through exchange rate pegging".

Given that a reputational equilibrium exists under *symmetric* information, the expected welfare gains from the implementation of the crawling peg $\{\hat{e}_t(\pi_t^{prec}, \pi_t^*)\}$ compared to targeting the domestic precommitment inflation rate are twofold. First, the imported higher precision with which the foreign authority can presumably control inflation results in a reduction of the variance of domestic inflation. Second, the elimination of the inflationary bias due to *asymmetric* information improves expected social welfare. The magnitude of the latter effect depends on whether a reputational equilibrium exists under *asymmetric* information:

1. *Expected social welfare gain when a reputational equilibrium exists under asymmetric information [case 1. above]:*

$$E_0^{asym}\Big(L(\text{inf. targ.}) - L(\text{craw. peg})\Big) = \sum_{t=0}^{\infty} \frac{p_t}{(1+\delta)^t} E_0^{sym}\left(L_t^{disc} - L_t^{prec}\right) + \left(\frac{1+\delta}{\delta}\right)^t \left(\sigma_\epsilon^2 - \sigma_{\epsilon^*}^2\right). \quad (41)$$

2. *Expected social welfare gain when a reputational equilibrium does not exist under asymmetric information [case 2. above]:*

$$E_0^{asym}\Big(L(\text{inf. targ.}) - L(\text{craw. peg})\Big) = E_0^{sym}\left(L^{disc} - L_0^{prec}\right) + \left(\frac{1+\delta}{\delta}\right)^t \left(\sigma_\epsilon^2 - \sigma_{\epsilon^*}^2\right). \quad (42)$$

These expressions show the extent to which the "credible purchase of credibility" improves expected social welfare. Moving on, we now consider fixed exchange rate pegs.

4.2.2 An Exchange Rate Peg with a Fixed Parity

When a fixed peg is implemented, the rate of nominal exchange rate depreciation is zero and the domestic country imports the suboptimally low foreign inflation rate. Given that a reputational equilibrium exists under *symmetric* information, the expected welfare gain from pegging the nominal exchange rate to the foreign currency under *asymmetric* information is equal to:

$$E_0^{asym}\Big(L(\text{inf. targ.}) - L(\text{peg})\Big) = E_0^{asym}\Big(L(\text{inf. targ.}) - L(\text{craw. peg})\Big) \\ -E_0^{asym}\Big(L(\text{peg}) - L(\text{craw. peg})\Big), \quad (43)$$

where:

$$E_0^{asym}\Big(L(\text{craw. peg})\Big) = E_0^{sym}\Big(L^{prec}\Big),$$

$$E_0^{asym}\Big(L(peg)\Big) = \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t}\Big(\tau_t^{peg} + \alpha\beta\pi_t^*\Big) > E_0^{sym}\Big(L^{prec}\Big)$$

and $\{\tau_t^{peg}\}$ is the sequence of tax rates that minimizes expected social loss when the foreign inflation rates $\{\pi_t^*\}$ are imported. From the first order conditions for optimality, $\{\tau_t^{peg}\}$ can entirely be characterized by:

$$\tau_t^{peg} = \left(\frac{1+\delta}{1+r}\right)^t \tau_0^{peg}, \quad (44.a)$$

$$\tau_0^{peg} = \frac{(1+r)^2 - (1+\delta)}{(1+r)^2}\left[\mathcal{G} - \alpha\beta\sum_{t=0}^{\infty}\frac{1}{(1+r)^t}\pi_t^*\right]. \quad (44.b)$$

We see that the expected reduction of social loss from the implementation of a pegged exchange rate system with a fixed parity is smaller than the expected reduction of social loss from a properly designed crawling peg when the foreign country has an optimal tax mix different from the domestic country. If the expected welfare loss from the adoption of the suboptimal foreign tax mix is smaller than the expected welfare gain from the elimination of the inflationary bias as a consequence of *asymmetric* information, a fixed peg can still be implemented as a reputational equilibrium. In this case the nominal exchange rate peg is endogenously time consistent and therefore credible. In the opposite case, a fixed peg rate system can even result in higher expected social losses than a floating rate system and is thus not credible.

It should be stressed that even if a pegged exchange rate system with a fixed parity is credible, it in general has poorer welfare properties than a properly designed crawling peg within our model. This result confirms Dornbusch's (1988) recommendation that countries with radically different optimal tax structures should not implement a nominal exchange rate peg with a fixed parity but should rather adopt the crawling peg that properly accounts for the domestic public finance situation.

5 Conclusion

In this paper, the time consistency problem of monetary policy has been studied within a simple open economy model of optimal taxation, in which inflation is affected by stochastic disturbances, implying imperfect control over the inflation rate by the policy maker. In the realistic *asymmetric* information scenario, the realizations of the stochastic disturbances to the inflation rate are private information of the policy maker. An inflationary bias then arises in a reputational equilibrium when the inflation rate is targeted. It has been shown that the resulting expected welfare loss from *asymmetric* information can be eliminated through the implementation of a crawling nominal exchange rate peg vis–a–vis a foreign country's currency, provided that the foreign authority has access to a precommitment technology and that a reputational equilibrium under *symmetric* information exist. In this case, the implementation of the precommitment outcome through the properly designed crawling peg is an endogenously time consistent reputational equilibrium under *asymmetric* information and the domestic country can "credibly purchase credibility" from the precommited foreign authority.

In addition, if the optimal tax mixes do not differ by too much between the two countries and if a reputational equilibrium exists under *symmetric* information, a nominal exchange rate peg with a fixed parity has also been shown to be implementable as a reputational equilibrium under *asymmetric* information. For this to hold true, the induced expected welfare losses from accepting the domestically suboptimal foreign tax mix must be overcompensated by the expected welfare gain through the elimination of the inflation bias due to *asymmetric* information. A nominal exchange rate peg then is credible. However, while it is welfare superior to targeting the domestic inflation rate in this case, it generally has poorer welfare properties than the crawling peg designed so as to achieve the domestically optimal inflation rate instead of just importing the foreign inflation rate.

It should be stressed that the difference between *symmetric* and *asymmetric* information may *endogenously* lead to the scenario that has frequently been assumed in the literature on the EMS, notably that although inflation targeting is not credible (resulting in the discretionary equilibrium), pegging the nominal exchange rate to a foreign currency that is governed by a precommited policy maker is credible. It is in this sense that the present paper extents the existing literature and in particular the recent analysis of de Kock and Grilli (1993).

The results of this paper appear to be of relevance beyond the discussion of the recent EMS–experience. For instance, the "purchase of credibility" may be one explanation for why many countries in central America or why Austria and the northern neighbors of the European community have found it advantageous to peg their nominal exchange rate unilaterally to the U.S. dollar or an EMS currency, respectively.[40] The choice of an appropriate exchange rate regime is also likely to become an important issue for Mexico and for the Eastern European countries. According to the results found above, a fixed pegged nominal exchange rate system is not likely to improve expected welfare for these countries, since they are obviously heavily dependent on seigniorage revenues.[41] Consequently the optimal inflation rates for these countries are higher than the ones in the countries they will possibly peg their nominal exchange rate to (Germany or the U.S.A.). A crawling peg would therefore seem to be the right regime to implement in order to import credibility. Of course necessary prerequisites are that central banks build up a stock of international reserves sufficient to defend the crawling peg and that disciplined fiscal policies, which are consistent with the crawling peg, are followed. In addition to eliminating the inflationary bias from *asymmetric* information, another expected welfare gain is then likely to accrue from a crawling peg, because the central banks in Germany or the U.S.A. can presumably control the inflation rate much more accurately.[42]

Finally two limitations of the analysis carried out above should be men-

[40] In the latter case, this choice has certainly been motivated by the interest in joining the EU too.

[41] Compare Ortiz (1991) and Oblath and Valentinyi (1994), respectively.

[42] For a discussion of other issues related to the choice of the exchange rate systems in this regions, see Bofinger (1991), Bomhoff (1992), Bayoumi and Eichengreen (1994), and Edwards and Losada (1994).

tioned. First, there are clear problems applying the concept of trigger strategies, which was suggested by Friedman (1971) in oligopoly theory, to monetary policy games. Most importantly, trigger strategies are not unique and hence there is no unique equilibrium; consequently it is not clear how the atomistic private sector can coordinate on any particular equilibrium.[43] Second, in order to maintain analytical tractability, the analysis has only focused on the credibility effects of the exchange rate regime. Of course other aspects as well are likely to affect expected social welfare:[44] On the one hand, the presumably negative effects of exchange rate uncertainty on international trade and investment would support the case for the implementation of a credible nominal exchange rate peg. On the other hand, under a pegged exchange rate system it is impossible to accommodate terms of trade shocks that hit the domestic country only, yielding a loss of expected welfare.[45] Modeling these effects on social welfare is beyond the scope of the present paper, but they should be kept in mind as important qualifications of the results derived here.

Appendix A

In this appendix, we characterize the optimal policy and determine the expected social loss under *symmetric* information, provided the government deviates from the precommitment solution. To do this, we substitute the first order conditions for $\{\tau_t^{dev}\}$ and $\{\pi_t^{dev}\}$ into (18), which delivers an expression

[43] Note that recently al Nowaihi and Levine (1994) showed how at least the length of the punishment period can be derived endogenously. In Herrendorf (1994a), I take up this idea in Canzoneri's (1985) version of the Barro–Gordon–type framework and discuss similar issues as in the present paper. Moreover, in Herrendorf (1994b) I show that the idea of the present paper carries over to a Cukierman–Meltzer–type monetary policy model with asymmetric information about a stochastic component of the government's objective, which reflects political instability [Cukierman and Meltzer (1986a,1986b)]. Even though the foreign policy maker has *discretion* in this model, credibility can be purchased through a crawling peg when the foreign country is politically more stable. This result suggests that the informational advantage of pegged exchange rate systems under *asymmetric* information should apply to fairly general situations, provided the policy maker finds it in his favor to minimize the ambiguity about his type or his actions.

[44] Compare the literature on common currency areas. Masson and Taylor (1992) provide a recent review.

[45] See Devarajan and Rodrick (1991) for a more detailed discussion.

for π_0^{dev} in terms of the exogenous parameters and of π_0^{prec}:

$$\pi_0^{dev} = \frac{\alpha\Big[(1+r)^2-(1+\delta)\Big]}{(c+\alpha^2)(1+r)^2-\alpha^2(1-\beta)(1+\delta)}\Big[\mathcal{G}+\alpha(1-\beta)\pi_0^{prec}\Big]. \quad \text{(A.1)}$$

Using the first order conditions and (A.1), explicit expressions for all elements from $\{\tau_t^{dev}\}$ and $\{\pi_t^{dev}\}$ can be derived. The expected social loss when the policy maker deviates can then be expressed as a function of π_0^{dev},

$$E_0^{sym}(L^{dev}) = \frac{c(c+\alpha^2)(1+r)^2}{\alpha^2\Big[(1+r)^2-(1+\delta)\Big]}\left(\pi_0^{dev}\right)^2 + c\left(\frac{1+\delta}{\delta}\right)\sigma_\epsilon^2. \quad \text{(A.2)}$$

Similarly, the expected loss under precommitment, (11) can be expressed in terms of π_0^{prec},

$$E_0^{sym}\left(L^{prec}\right) = \frac{c\Big[c+(\alpha\beta)^2\Big](1+r)^2}{\alpha^2\Big[(1+r)^2-(1+\delta)\Big]}\left(\frac{\pi_0^{prec}}{\beta}\right)^2 + c\left(\frac{1+\delta}{\delta}\right)\sigma_\epsilon^2. \quad \text{(A.3)}$$

Using (A.2) and (A.3), the condition for the existence of a reputational equilibrium under symmetric information, (21), can be rewritten to:

$$0 \leq \frac{c(1+r)^2}{\alpha^2\Big[(1+r)^2-(1+\delta)\Big]}\left[\left(c+\alpha^2\right)\left(\pi_0^{dev}\right)^2 - \left(c+(\alpha\beta)^2\right)\left(\frac{\pi_0^{prec}}{\beta}\right)^2\right]. \quad \text{(A.4)}$$

For any given set of parameter values this condition is straightforward to check. However, it is not obvious to derive an explicit general condition from (A.4) because, as is straightforward to check, (7) implies that π_0^{dev} is always smaller than π_0^{prec}/β. We will therefore only show that for some parameter values a reputational equilibrium does exist whereas it does not for others.

To see this, consider the case when β approaches zero. From (10) it immediately follows that $\lim_{\beta\to 0}\pi_0^{prec} = 0$. Using this and (A.1), condition (A.4) can in the limit be written as:

$$c\left[\frac{\alpha\Big[(1+r)^2-(1+\delta)\Big]}{c(1+r)^2}\mathcal{G}\right]^2 \leq (c+\alpha^2)\left[\frac{\alpha\Big[(1+r)^2-(1+\delta)\Big]}{(c+\alpha^2)(1+r)^2-\alpha^2(1+\delta)}\mathcal{G}\right]^2, \quad \text{(A.5)}$$

which is equivalent to:[46]

$$\frac{\alpha^2\Big[(1+r)^2-(1+\delta)\Big]^2}{(1+r)^2\Big[2(1+\delta)-(1+r)^2\Big]} \le c. \tag{A.6}$$

In the limit, (A.4) is therefore violated for all c that violate (A.6). By the continuity of $E_0^{sym}(L^{dev} - L^{prec})$, we conclude that there must exist a β–neighborhood of zero, in which a reputational equilibrium does not exist, provided c does not satisfy (A.6). This is plausible because if $\beta \approx 0$, the marginal revenues from anticipated inflation are negligible and the difference between the revenues from anticipated and unanticipated inflation is maximal, giving the authority the maximal incentive to collect revenues from surprise inflation. It will do so when the marginal cost c from surprise inflation are not too large compared to the marginal revenue α. In contrast, if c is large relative to α, that is, if c satisfies (A.6), the creation of surprise inflation is not welfare improving. There then must exist a neighborhood of zero such that a reputational equilibrium exists for β being from that neighborhood.[47]

Appendix B

In this appendix, the optimal tax and inflation rates for a given π_0^{dev} are determined, depending on whether, after an inflation surprise, the policy maker loses his reputation in period zero or in period one.

i) *Reputation is lost in period zero:*

In this case, the optimal policy for any given π_0^{dev} has to minimize

$$\left(\bar{\tau}_0^{dev}\right)^2 + \sum_{t=1}^{\infty}\left(\frac{1}{1+\delta}\right)^t \left[\left(\bar{\tau}_t^{dev}\right)^2 + c\left(\bar{\pi}_t^{dev}\right)^2\right] \tag{B.1}$$

subject to:

[46]Note that the additional but innocuous assumption $2(1+\delta) > (1+r)^2$ is necessary to show this.

[47]It may be observed that independent of the other parameters, a reputational equilibrium exists when c becomes very large. This holds true because $\lim_{c\to\infty} E_0^{sym}(L^{prec} - L^{dev}) = 0$.

$$\mathcal{G}(\pi_0^{dev}) := \mathcal{G} - \alpha(\pi_0^{dev} - \pi_0^{prec}) - \alpha\beta\pi_0^{prec} \tag{B.2}$$
$$= \bar{\tau}_0^{dev} + \frac{1}{1+r}\Big[\bar{\tau}_1^{dev} + \alpha\Big(\bar{\pi}_1^{dev} - \pi_1^{prec}\Big) + \alpha\beta\pi_t^{prec}\Big]$$
$$+ \sum_{t=2}^{\infty}\left(\frac{1}{1+r}\right)^t \Big[\bar{\tau}_t^{dev} + \alpha\Big(\bar{\pi}_t^{dev} - (\bar{\pi}_t^{dev})^e\Big) + \alpha\beta(\bar{\pi}_t^{dev})^e\Big],$$

where the given inflation expectation $(\bar{\pi}_t^{dev})^e$ is equal to $\bar{\pi}_t^{dev}$ $\forall t \geq 2$. Using the first order conditions for optimality, the solution to this problem can for any given π_0^{dev} completely be characterized by the following expressions $(t = 1, 2, \ldots)$:

$$\bar{\tau}_t^{dev} = \left(\frac{1+\delta}{1+r}\right)^t \bar{\tau}_0^{dev}, \tag{B.3}$$
$$\bar{\pi}_t^{dev} = \left(\frac{1+\delta}{1+r}\right)^{t-1} \bar{\pi}_1^{dev}, \tag{B.4}$$
$$\bar{\pi}_t^{dev} = \frac{\alpha}{c}\bar{\tau}_t^{dev}, \tag{B.5}$$
$$\bar{\tau}_0^{dev} = \frac{c(1+r)^2\Big[(1+r)^2-(1+\delta)\Big]\Big[\mathcal{G}(\pi_0^{dev})+\frac{(1-\beta)\alpha}{1+r}\pi_1^{prec}\Big]}{c(1+r)^4+\alpha^2(1+\delta)\Big[(1+r)^2-(1-\beta)(1+\delta)\Big]}. \tag{B.6}$$

ii) *Reputation is lost in period one:*

The optimal policy for any given π_0^{dev} then has to minimize

$$\left(\tilde{\tau}_0^{dev}\right)^2 + \sum_{t=1}^{\infty}\left(\frac{1}{1+\delta}\right)^t \left[\left(\tilde{\tau}_t^{dev}\right)^2 + c\left(\tilde{\pi}_t^{dev}\right)^2\right] \tag{B.7}$$

subject to:

$$\mathcal{G}(\pi_0^{dev}) = \mathcal{G} - \alpha(\pi_0^{dev} - \pi_0^{prec}) - \alpha\beta\pi_0^{prec} \tag{B.8}$$
$$= \tilde{\tau}_0^{dev} + \sum_{t=1}^{\infty}\left(\frac{1}{1+r}\right)^t \Big[\tilde{\tau}_t^{dev} + \alpha\Big(\tilde{\pi}_t^{dev} - (\tilde{\pi}_t^{dev})^e\Big) + \alpha\beta(\tilde{\pi}_t^{dev})^e\Big],$$

where the given inflation expectation $(\tilde{\pi}_t^{dev})^e$ is equal to $\tilde{\pi}_t^{dev}$ $\forall t \geq 1$. In this case, the optimal sequences of tax and inflation rates for a given π_0^{dev}

is characterized by the expressions ($t = 1, 2, \ldots$):

$$\tilde{\tau}_t^{dev} = \left(\frac{1+\delta}{1+r}\right)^t \tilde{\tau}_0^{dev}, \tag{B.9}$$

$$\tilde{\pi}_t^{dev} = \left(\frac{1+\delta}{1+r}\right)^{t-1} \tilde{\pi}_1^{dev}, \tag{B.10}$$

$$\tilde{\pi}_t^{dev} = \frac{\alpha}{c}\tilde{\tau}_t^{dev}, \tag{B.11}$$

$$\tilde{\tau}_0^{dev} = \frac{c\left[(1+r)^2 - (1+\delta)\right]}{c(1+r)^2 + \alpha^2\beta(1+\delta)}\mathcal{G}(\pi_0^{dev}). \tag{B.12}$$

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