Monetary policy regimes with hybrid output gaps and inflation rates with an application to EU-accession countries *

Giovanni Di Bartolomeo
University of Rome "La Sapienza"

Bruno Merlevede
University of Ghent

Joseph Plasmans†
University of Antwerp and Tilburg University

Bas van Aarle
University of Leuven and University of Nijmegen

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Abstract

This paper studies implications of alternative monetary policy regimes as discretionary and commitment policy rules for (relatively) closed and small open economies.

For each of these two economy types a model with possible frictions in nominal prices (and wages) is constructed. Such a model is suited for the study of effects of monetary policy rules on inflation rates and output gaps and allows for forward- and backward-looking behavior when determining inflation and output dynamics.

We consider each of the EU-accession CEECs as a small open economy being largely dependent on external shocks and evaluate the empirical size of forward- and backward-looking expectations in these countries. Moreover, we verify whether output gaps and deviations of marginal costs from their equilibrium are good approximations of each other in estimates of hybrid versions of the New Keynesian Phillips curve.

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†Corresponding author, Faculty of Applied Economics UFSIA-RUCA, University of Antwerp, Prinsstraat 13, B2000 Antwerp; Phone: +32 (0)3 220 4149, Fax: +32 (0)3 220 4585, Email: joseph.plasmans@ua.ac.be.

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1 Introduction

Many of the Central and Eastern European countries (CEECs) are evolving according to a path that drives them into the European Union (EU) by May 2004. Indeed, their application to the EU constitutes a commitment to the "Acquis Communautaires" for these countries, which accelerates their ongoing transformation process from a planned to a market economy. This fact has an important relevance for their structural policy and reforms. Their EU-accession has also a strong impact in terms of commitments in the management of monetary and exchange rate policies. This paper studies implications of alternative monetary policy regimes for small open economies like the CEECs from theoretical and empirical points of view.

We build a theoretical model to analyze output gaps and inflation in accession countries under a number of alternative settings of monetary policy. We consider each of the accession countries as a small open economy, which is significantly affected by external shocks, by following the recent literature on this issue (e.g. Clarida (2001), Clarida *et al.* (2001), Clarida *et al.* (2002), Galì and Monacelli (2002), Smets and Wouters (2002a), and Caputo (2003)). A focus lies on the effects of both backward- and forward-looking behavior, since both specifications seem to be important to understand the inflation and real output dynamics of these countries.

In the empirical part, we test the importance of forward- versus backward-looking behavior for these EU-accession countries. In fact, many critical assessments of the New Keynesian paradigm have been concentrated on the forward-looking nature of the inflation dynamics embedded in it. In particular, many authors point out that the pattern of dynamic cross-correlation between inflation and de-trended output observed in the data suggests that output leads inflation (Fuhrer and Moore (1995)). However, the de-trended gap is a distorted proxy of the output gap involved in the Phillips curve of New Keynesian models (e.g. Galí and Gertler (1999) and Sbordone (2002)). As a way to overcome these problems we also directly estimate the inflation dynamics as a function of the marginal cost of labor as it is directly derived from the micro-foundations of the model (see Galí and Gertler (1999), Galí *et al.* (2001), Gertler *et al.* (2001), Jondeau and Le Bihan (2001), Leith and Malley (2002), and Sbordone (2002) for closed-economy versions of such estimates). Some preliminary evidence for EU-accession countries is provided by Arratibel *et al.* (2002). However, their estimations are based on a pooled sample that merges all the accession countries together without taking account of the institutional differences and of the different demand and supply side features of these countries. We will take account of the heterogeneity of the EU-accession countries explicitly.

Summarizing, we exploit the monetary policy design problem within a simple baseline theoretical framework, which takes account of the fundamental elements characterizing the accession countries, like their small size and high degree of openness in particular to the current EU, and their possible (monetary and economic) behavior based on both forward- and backward-looking expectations. In such a context, we consider the implications of adopting alternative monetary policy regimes as discretionary and commitment optimal policy rules.

The paper is organized as follows. In section 2 the theoretical setup is presented, based in the first instance on a linearized closed-economy model being a direct generalization of the common New Keynesian model with sticky prices described in Galí *et al.* (1999) that also takes account of the backward-looking behavior of output gaps and inflation rates. Hence, the behavior of the private sector is described by two equations which involve both forward- and backward-looking behavior. Following a recent strand of literature, we call such behavior "hybrid". Finally, we extend this approach to an open economy framework. Section 3 discusses econometric estimates of the derived output gap and inflation equations, involving both forward- and backward-looking dynamics through the Generalized Method of Moments (GMM) using a recent database of quarterly data for the EU-accession countries. Finally, section 4 contains some concluding remarks.

2 The Theoretical Framework

2.1 The basic generalized framework

Economists use increasingly dynamic New Keynesian stochastic general equilibrium (DSGE) models for macroeconomic analysis. In order to solve these models and keep them tractable models with linear rational expectations (LREs) are typically used as local approximations. We use hybrid LREs models with backward- and forward-looking LREs for output gaps and inflation in this paper.

In this section the theoretical setup for hybrid versions of output-gap and inflation equations is derived as a direct generalization of the closed-economy New Keynesian model with sticky (nominal) prices described in Galí *et al.* (1999). This derivation is presented both for a closed-economy framework as for an open-economy one.

To start with the closed-economy setup, it is assumed that the demand side of the (closed) economy is given by a hybrid output-gap equation:

$$\widehat{y}_t = \pi_1 E_t\left[\widehat{y}_{t+1}\right] + \pi_2 \widehat{y}_{t-1} - \alpha(r_t - E_t\left[\Delta p_{t+1}\right] - rr_t^0) + u_t \tag{1}$$

which is a dynamic generalization of an IS curve derived from consumer optimization in the presence of habit formation. In equation (1) $\widehat{y}_t \equiv y_t - y_t^0$ is the output gap defined as the difference between the actual output and the potential output,[1] r_t is the nominal interest rate, Δp_t is the inflation rate (i.e. the change

[1] Potential output is the output that would have been realized when no (nominal price) rigidities were present.

in logarithmic prices), rr_t^0 is the potential or steady-state real interest rate, u_t is a stochastic error term,[2] and E_t denotes the private sector's (conditional) expectation operator, given the information available at time t for the output gap and the inflation rate next period.

The supply side of the (closed) economy is assumed to be described by a hybrid Phillips curve:

$$\Delta p_t = \beta_1 E_t \left[\Delta p_{t+1}\right] + \beta_2 \Delta p_{t-1} + \gamma \widehat{y}_t + v_t \tag{2}$$

which is the price-setting rule for the monopolistically competitive firms facing constraints on the frequency of future price changes and where v_t is a stochastic error term.[3]

The above hybrid Phillips curve is very general since it can be reduced to the traditional Phillips curve by assuming $\beta_1 = 0$ and $\beta_2 = 1$, to the Taylor (1993) forward-looking Phillips curve by assuming $\beta_1 = 1$ and $\beta_2 = 0$, to the Fuhrer and Moore (1995) forward- and backward-looking Phillips curve with two-period contracts by assuming $\beta_1 = \beta_2 = \frac{1}{2}$ or to the standard (or core) New Keynesian Phillips curve (NKPC) by assuming $\beta_2 = 0$.

The two following subsections analyze (optimal) monetary policies, where hybrid equations as (1) and (2) for a closed economy are derived and open-economy extensions are considered. The last subsection discusses a New Keynesian open-economy setup.

2.2 A New Keynesian closed-economy setup

Assuming that $\pi_1 = 1$, $\pi_2 = 0$, $\beta_1 = \beta$, $\beta_2 = 0$ in (1) and (2) , we obtain the two structural equations of the standard New Keynesian sticky-price model for *closed* economies, which consists of an 'expectational IS curve' or a demand equation derived from an Euler equation for the optimal timing of purchases and an aggregate supply equation derived from a first-order condition for optimal Calvo-type price-setting:[4]

$$\begin{aligned} \widehat{y}_t &= E_t \left[\widehat{y}_{t+1}\right] - \alpha \left(r_t - E_t \left[\Delta p_{t+1}\right] - rr_t^0\right) + u_t && (3) \\ \Delta p_t &= \beta E_t \left[\Delta p_{t+1}\right] + \gamma \widehat{y}_t + v_t \quad , && (4) \end{aligned}$$

[2] In general, u_t represents a shock to government purchases and/or potential output.

[3] The stochastic error term v_t represents any cost-push shock to inflation other than that entering through $\widehat{y}_t$. Notice that, in practice, it is often impossible to identify the source of stochastic disturbances to inflation, in particular whether an inflation shock is a supply shock or a cost-push shock (see Smets and Wouters (2003)).

[4] It is well known that LREs models as this standard New Keynesian sticky-price model for closed economies (see e.g. Clarida *et al.* (2001)) can have multiple equilibria and, hence, are (generally) indeterminate. In the case of such indeterminacy it is generally possible to construct sunspot equilibria in which stochastic disturbances that are unrelated to fundamental shocks influence the model dynamics. There are only very few empirical studies about the importance of indeterminacy in macroeconomic models. A very recent example is Lubik and Schorfheide (2002) who use a Bayesian analysis where the indeterminacy hypothesis is evaluated by the posterior probability of the parameter region for which there exist multiple stable equilibria.

where an appealing characteristic of the core output-gap equation and NKPC ((3) and (4)) is that they can be derived from firms' and households' optimizing price setting and consumption behavior under market equilibrium. This optimizing behavior leads to cross-equation restrictions between (3) and (4), which can be illustrated from the application of the open-economy analysis in the Appendix to a closed-economy setting.[5] As mentioned before, we utilize a Calvo (1983) price-adjustment process to model price stickiness as a restriction on the firms' ability to adjust prices and wages in a perfectly competitive and, hence, flexible manner. Assuming market equilibrium the aggregate demand for output can be defined as: $Y_t \equiv C_t + G_t$, with C_t the aggregate private consumption and G_t the aggregate government consumption, or $C_t = Y_t(1 - \frac{G_t}{Y_t})$, i.e.

$$\log C_t = c_t = \log Y_t + \log(1 - \frac{G_t}{Y_t}) = y_t - g_t \tag{5}$$

with $g_t \equiv -\log(1 - \frac{G_t}{Y_t})$. If deviations from the steady state are considered, the variables are denoted with a hat, as e.g. for the output gap $\widehat{y}_t$. Since, moreover, government spending is assumed to remain always at its steady-state level (see e.g. Leith and Malley (2002), p. 10), $\widehat{g}_t = 0$ so that $\widehat{c}_t = \widehat{y}_t$. Summarizing, the IS-curve (3) is derived under market equilibrium and from expressing the logarithmized Euler consumption equation (55) in the Appendix for all consumers as a deviation from its steady state, where it is assumed that $rr_t^0 \equiv -\log\beta = rr^0$:

$$\widehat{y}_t = E_t\left[\widehat{y}_{t+1}\right] - \frac{1}{\sigma}\left(r_t - E_t\left[\Delta p_{t+1}\right] - rr_t^0\right) + \underbrace{E_t\left[\Delta g_{t+1} - \Delta y_{t+1}^0\right]}_{g_t^{'}} \tag{6}$$

with σ a parameter of relative risk aversion of households (in the parametric household's utility function (47) in the Appendix) and $g_t^{'}$ a (current) demand shock being a function of expected changes in government purchases relative to expected changes in potential output, which can be interpreted as an autocorrelated disturbance term ($g_t^{'}$ being u_t in (3)) that obeys:

$$g_t^{'} = \rho_g g_{t-1}^{'} + \varepsilon_t^g$$

with $0 \leqq \left|\rho_g\right| \leqq 1$ and ε_t^g a white noise stochastic error term with zero mean and constant variance σ_g^2. Assuming now that firms set prices on a staggered basis as in Calvo (1983), each period only a fraction of firms receives a signal to reset prices optimally so that the following closed-economy NKPC is obtained (see Clarida *et al.* (1999) and Galí *et al.* (2001)):

$$\Delta p_t = \beta E_t\left[\Delta p_{t+1}\right] + \lambda\widehat{mc}_t + v_t' \tag{7}$$

[5] And by taking account of the property that the output gap will generally be negative (because the monopolistic competition, assumed to exist on the intermediate goods market, generally introduces inefficiency so that the output produced will in general be lower than the perfectly competitive output).

where $\widehat{mc}_t$ is the logarithmic (real) marginal cost, defined as a deviation from its steady-state level, and v'_t is determined by the following autocorrelated process:

$$v'_t = \rho_\nu v'_{t-1} + \varepsilon_t^\nu$$

with $0 \leqq |\rho_v| \leqq 1$ and ε_t^ν is a white noise stochastic error term with zero mean and constant variance σ_ν^2. For a production function of the Cobb-Douglas form, $Y_t(z) = A_t(N_t(z))^{1-\alpha}$, the parameter λ is determined by the model's structural parameters as follows:

$$\lambda = \frac{(1-\theta_p)(1-\beta\theta_p)(1-\alpha)}{\theta_p[1+\alpha(\theta-1)]}$$

where θ_p is a measure of the degree of price rigidity in the Calvo-sense (where each firm is assumed to reset its price with probability $(1-\theta_p)$ so that prices are fixed for an expected period of $\frac{1}{1-\theta_p}$),[6] β is the discount factor of the private sector originating from the utility function (43) in the Appendix, α is a measure of the curvature of the production function (labor elasticity) and θ is the elasticity of demand (under the assumption that a company is confronted with an isoelastic demand curve for its product; see (45) and (57) in the Appendix). Note that $\frac{\theta}{\theta-1}$ is the firm's desired mark-up then.

Using the Cobb-Douglas production, the real marginal cost in period $t+k$ of a company setting its price optimally in period t is determined, using (78) of the Appendix, as:

$$MC_{t,t+k} = \frac{(W_{t+k}/P_{t+k})}{(1-\alpha)(Y_{t,t+k}/N_{t,t+k})} \tag{8}$$

where $Y_{t,t+k}$ and $N_{t,t+k}$ are the output and employment for a company that optimaly sets its price in period t. Averaging over all companies (assuming equal technology A_t) we have:

$$MC_t = \frac{(W_t/P_t)}{(1-\alpha)(Y_t/N_t)} \tag{9}$$

In the simpler Leontief case, $Y_t(z) = A_t N_t(z)$, the marginal cost can be found by setting α equal to 0 in (9). For this technology, the parameter λ as a function of the structural parameters reduces to:

$$\lambda = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$$

[6] The staggered price setting according to Calvo (1983) assumes that during each period t only a fraction $(1-\theta_p)$ of producers reset their prices optimally, while a fraction θ_p keep their prices unchanged. While fixing the reset price the individual firm takes the probability of being stuck with the new reset price for s periods into account. Let $\widetilde{p}_t$ denote the logarithm of the price set by firms adjusting prices in period t, then the evolution of the logarithmic price level over time can be written as the following 'rule of thumb', which is a difference equation in log-linear terms: $p_t = \theta_p p_{t-1} + (1-\theta_p)\widetilde{p}_t$.

The deviation of the marginal cost from its steady state value can be shown to be linked to the output gap as follows (see e.g. Gali (2002)):

$$\widehat{mc}_t = (\sigma + \phi)\,\widehat{y}_t$$

where ϕ is the inverse of the intertemporal elasticity of work effort with respect to the real wage in the disutility of work $U_2(N_t)$ of the parametric utility function (47) in the Appendix.

Now, the monetary policy targets will be derived. Optimal monetary policy at a generic time T is derived from the minimization of a quadratic expected loss function:

$$L_T = \frac{1}{2} E_T \left[\sum_{i=0}^{\infty} \delta^i \left((\Delta p_{T+i})^2 + b\widehat{y}_{T+i}^2 \right) \right] \qquad (10)$$

subject to the above output-gap and inflation-rate equations.[7] In equation (10) b is the relative weight for output-gap stabilization[8] and $\delta \in (0,1)$ is the central bank's constant intertemporal discount factor. The minimization of (10) is often called 'flexible inflation targeting' in the literature (see Svensson (1999)). In addition, notice that $b = 0$ corresponds to strict inflation targeting.

The policy problem consists in choosing the path for the central bank's instrument, r_t, assuring the paths of the target variables, Δp_t and $\widehat{y}_t$, that minimize the expected loss function (10) subject to the constraints on output gap and inflation rate behavior implied by equations (3) and (4), *viz.* (6) and (7). We solve this policy problem in two stages. First, we determine the optimal relationship between the targets by minimizing (10) with respect to equation (4), *viz.* (7). Second, we use the optimal relationship, resulting from the first stage, and equation (3) (*viz.* (6)) to find the optimal path for the interest rate that supports the optimal condition. Using this two-stage specification of the policy problem, optimal monetary policy reduces to a sequence of static problems in the first stage. In fact, the central bank's problem can easily be solved in this first stage by deriving a minimax solution of the following Lagrangian:

$$\Gamma_T := L_T + \sum_{i=0}^{\infty} \delta^i \lambda_{T+i} \left\{ \beta E_T \left[\Delta p_{T+1+i} \right] + \gamma \widehat{y}_{T+i} + v_{T+i} - \Delta p_{T+i} \right\}$$

to which corresponds the following first-order (minimizing) conditions with re-

[7] Notice that the target value of the inflation rate can be set at zero, implying that the classical problem of inflation bias does not arise. Alternatively, we could also assume a constant inflation bias $\overline{\Delta p}$. Moreover, the output target level is set at the flexible-price output level.

[8] A socially optimal output gap $\widehat{y}^*$ may also be considered in (10) so that the second term can be replaced by $b(\widehat{y}_{T+i} - \widehat{y}^*)^2$. For reasons of simplicity, $\widehat{y}^*$ may be assumed to be constant and positive if potential output on average, due to some distortion, falls short of the socially optimal output level and negative in the opposite case.

spect to the observable variables:[9]

$$\frac{\partial \Gamma_T}{\partial \Delta p_T} = \Delta p_T - \lambda_T = 0 \tag{11}$$

$$\frac{\partial \Gamma_T}{\partial \Delta p_{T+i}} = E_T\left[\delta\left(\Delta p_{T+i} - \lambda_{T+i}\right) + \beta \lambda_{T+i-1}\right] = 0 \qquad i = 1, 2, 3.. \tag{12}$$

$$\frac{\partial \Gamma_T}{\partial \widehat{y}_{T+i}} = E_T\left[b \widehat{y}_{T+i} + \gamma \lambda_{T+i}\right] = 0 \qquad i = 0, 1, 2... \tag{13}$$

We solve these FOCs under both the discretionary and commitment regimes. Under discretion, the central bank is assumed to re-optimize during each period. Under commitment, the central bank implements a state-contingent rule to which it can credibly commit. With forward-looking price setting and the underlying short-run output-inflation trade-off, there may be gains from commitment to a rule, as emphasized by Clarida *et al.* (1999) and others. The **discretionary policy** is obtained by considering equations (11) and (13) to which corresponds the following optimal general condition:

$$\Delta p_t = -\frac{b}{\gamma} \widehat{y}_t \tag{14}$$

As underlined by Clarida *et al.* (1999), this condition implies that the central bank follows a "lean against the wind policy". Whenever output is below capacity, the central bank reduces the interest rate to expand the demand (and inflation) and vice-versa when it is above target. Clearly, the more the central bank is then concerned about inflation, the less its reaction is. In a similar way, the monetary policy under the **commitment regime** must satisfy the following optimal general condition derived from equations (12) and (13):

$$\Delta p_t = -\frac{b}{\gamma}\left(\widehat{y}_t - \frac{\beta}{\delta} \widehat{y}_{t-1}\right) \tag{15}$$

This commitment regime is called the 'timeless perspective' regime by Woodford (1999b), which involves ignoring any conditions prevailing at the regime's inception by imagining that the decision to apply (12) and (13) had been made in the distant past (the start-up condition (11) is not used and condition (12) is applied in all periods). In general, a policy rule is called 'optimal from a timeless perspective' if it has a time-invariant form and if commitment to the rule from any date T onward determines an equilibrium that is optimal, subject to at most a finite number of constraints on the initial evolution of the endogenous variables. Contrary to the 'pure commitment solution' Nelson and McCallum (2000) show that in this timeless perspective case there is no dynamic inconsistency in terms of the central bank's own decision-making process. Nevertheless, many economists reject the idea of any commitment as, up to now, no central bank has made a 'once and for all commitment' to a monetary policy rule.

[9] Notice that in the definition of the Lagrangean and in the first-order conditions (FOCs) we have used the law of iterated expectations: $E_T(E_t[x_{t+i}]) = E_T[x_{t+i}]$ for $t \geqslant T$.

Equations of the kind of (14) and (15) are sometimes called 'specific targeting rules' in the literature. Moreover, we also remark that, if the central bank discounts the future at the same rate as the private sector ($\beta = \delta$), equations (14) and (15) provide the standard optimal conditions (compare with Clarida *et al.* (1999)).

Taken together, the optimal condition (14) and the core NKPC (4) form a difference equation system that, solved,[10] yields the *optimal (reduced form) targets under the discretionary regime* (D); hence, for Δp_t^D and $\widehat{y}_t^D$:

$$\Delta p_t^D = \frac{b}{\gamma^2 + b(1-\beta\rho)} v_t \tag{16}$$

$$\widehat{y}_t^D = -\frac{\gamma}{\gamma^2 + b(1-\beta\rho)} v_t \tag{17}$$

where it is assumed that the stochastic inflation shock v_t is observable at time t and follows a first-order autoregressive process: $v_t = \rho v_{t-1} + \tilde{v}_t$.[11]

In the New Keynesian setup the inflation shock, v_t, can have two different interpretations (see Smets and Wouters (2002)). One interpretation is that this shock is driven by a technology shock that also affects the appropriate target level of output since the central bank's objective is given by (10) and another interpretation is that this inflation shock captures a wage-push shock as in Clarida *et al.* (2002).[12]

Similarly, from equations (15) and (4), we derive the *optimal targets in the commitment regime* (C):

$$\Delta p_t^C = -\frac{b}{\gamma}\left(\theta_1 - \frac{\beta}{\delta}\right)\widehat{y}_{t-1} - \frac{1}{\theta_2} v_t \tag{18}$$

$$\widehat{y}_t^C = \theta_1 \widehat{y}_{t-1} - \frac{\gamma}{b\theta_2} v_t \tag{19}$$

where $\theta_1 \equiv \frac{1}{2}\frac{\left(1+\beta+\gamma^2 b^{-1}\right)-\sqrt{\left(1+\beta+\gamma^2 b^{-1}\right)^2-4\beta}}{\beta}$ and $\theta_2 \equiv 1+\beta\left(\frac{\beta}{\delta}-\rho\right)+\frac{\gamma^2}{b}-\theta_1\beta$. Notice that in the commitment regime output persistence is present whereas in

[10] The difference equation system is solved by using the method of undetermined coefficients assuming rational expectations. In particular, we look for the minimal state variable solution that excludes bubbles and sunspots, as discussed by McCallum (1999).

[11] Where the (known) autocorrelation coefficient satisfies $0 < |\rho| < 1$ and $\tilde{v}_t \sim iid\left(0, \sigma_{\tilde{v}}^2\right)$ (see also before). Notice that in the presence of forward-looking private sector behavior discretionary optimization by a central bank generally results not only in average inflation bias when the output gap target is positive, but also in inefficient responses to shocks (that is called 'stabilization bias' by Clarida et al. (1999) and Woodford (1999a) and arises with a Calvo-type NKPC; see before), regardless of whether the output-gap target is positive or not.

[12] In Clarida *et al.* (2002) the inflation shock is modeled as a stochastic disturbance to the wage markup in a monopolistically competitive labor market. As this shock to the wage markup causes inefficient variations in output, a welfare-maximizing central bank would like to smooth out the output effects of such shocks. In that case the output gap in the central bank's quadratic risk function (10) is replaced by output alone. The cost-push shock will give rise to a trade-off between inflation and output-gap stabilization while a supply shock will not (see Gaspar and Smets (2002)).

the discretionary regime it is not (compare equations (16) and (17) with (18) and (19)).

By assuming that the stochastic shock u_t is observable at time t and may follow a first order autoregressive process: $u_t = \omega u_{t-1} + \tilde{u}_t$[13] and by plugging the reduced form expressions (16) and (17) in the aggregate demand (3) and, solving, we derive the *optimal (reduced form) feedback policy* for the interest rate (the central bank's (optimal) *reaction function*) in the *discretionary regime*:

$$r_t^D - rr_t^0 = \frac{1}{\alpha}\left[\frac{\gamma(1-\rho)+\alpha b\rho}{\gamma^2+b(1-\beta\rho)}\right]v_t + \frac{1}{\alpha}u_t \tag{20}$$

According to the optimal policy rule (20) the central bank adjusts the interest rate to stabilize demand and supply shocks subject to a trade-off between the output-gap volatility and the volatility of inflation. From (20) it becomes clear that the reaction of interest rates to demand shocks does not depend on the preference parameter b. Hence, any preference type of a central bank will choose the same reaction to demand shocks, which restores the optimal combination of a zero output gap and an inflation rate equal to the inflation target. The interest rate reaction to supply shocks on the contrary depends on central bank preferences. Hence, depending on the preference type each central bank will choose its preferred stabilization mix. This means that in situations with supply shocks the central bank faces a trade-off between stabilizing the inflation rate versus stabilizing the output gap (see before). Of course the deviation from baseline will only be one period long; hence, equation (20) is not able to display persistence.

By using equations (18) and (19) instead of equations (16) and (17), the central bank's (optimal) reaction function in the *commitment regime* becomes:[14]

$$\begin{aligned} r_t^C - rr_t^0 &= \frac{1}{\theta_2}\left[\frac{\gamma}{b}\left(\frac{1+\theta_1-\rho}{\alpha}\right) - \frac{\beta+\rho(\delta-\theta_1)}{\delta}\right]\widehat{y}_{t-1} + \theta_1\left[\frac{1+\theta_1}{\alpha}+\right. \\ &\quad \left. + \frac{b(\delta\theta_1-\beta)}{\gamma\delta}\right]v_t + \frac{1}{\alpha}u_t \end{aligned} \tag{21}$$

Again, equation (21) implies that the optimal response to demand shocks u_t does not depend on the preference parameter b. In other words, each preference type b will react identically to demand shocks, which is quite logical since our model does not exhibit any persistence (up to now) so that the central bank is able to restore its globally optimal outcome of an inflation rate equal to the inflation target and an output gap equal to zero.

[13] Where the (known) autocorrelation coefficient satisfies $0 < |\omega| < 1$ and the error terms are assumed to be mutually independently distributed as white noise processes, or $\tilde{u}_t \sim iid\left(0, \sigma_{\tilde{u}}^2\right)$ (see before for the process g_t').

[14] Again, by assuming that the central bank discounts the future at the same rate as the private sector, equations (20) and (21) yield the standard reaction functions after tedious algebra.

Notice that the above reaction functions do not assume the existence of a stable solution for all possible parameters (see Evans and Honkapohja (2002a) and (2002b)).

2.3 A hybrid closed-economy setup

The hybrid model is an alternative specification that is based on the presence of habit formation in consumption and tends to generate persistence in inflation and output.[15] We present two possible ways to determine a hybrid New Keynesian macroeconomic model.

First, a simple (*ad hoc*) approach to the hybrid model is suggested by Clarida *et al.* (1999). They introduce two parameters χ and φ ($0 \leqq \chi \leqq 1$ en $0 \leqq \varphi \leqq 1$): χ measures the influence of the lagged output gap (versus the expected future output gap); φ measures the importance of lagged inflation versus future inflation. Model (6) and (7) then becomes:

$$\widehat{y}_t = \chi E_t\left[\widehat{y}_{t+1}\right] + (1-\chi)\,\widehat{y}_{t-1} - \frac{1}{\sigma}\left(r_t - E_t\left[\Delta p_{t+1}\right] - rr_t^0\right) + g_t' \quad (22)$$

$$\Delta p_t = \varphi\beta E_t\left[\Delta p_{t+1}\right] + (1-\varphi)\,\Delta p_{t-1} + \lambda\widehat{mc}_t + v_t' \quad (23)$$

Again $\lambda\widehat{mc}_t$ can be interpreted using either a Leontief or a Cobb-Douglas technology.

Second, explicit profit maximization under a generalized Calvo - price setting and explicit utility maximization in the presence of habit formation in consumption is considered. The staggered price setting according to Calvo (1983) is now re-interpreted in the sense that firms reset prices with probability $(1-\theta_p)$, but that now only a fraction $(1-\omega)$ of firms actually behave according to the Calvo model. The remaining fraction ω is assumed to follow a backward-looking rule. If a firm maximizes its real profits, it will choose the price of its good so that the adjustment price is determined by the projected path of marginal cost with resulting NKPC (see Gali *et al.* (2001)):

$$\Delta p_t = \Pi_1 E_t\left[\Delta p_{t+1}\right] + \Pi_2 \Delta p_{t-1} + \lambda\widehat{mc}_t + v_t' \quad , \quad (24)$$

where, in the Cobb-Douglas case, we have:

$$\Pi_1 \equiv \beta\theta_p\Gamma^{-1} \text{ ; } \Pi_2 \equiv \omega\Gamma^{-1} \text{ ;}$$
$$\text{and } \lambda \equiv \frac{(1-\omega)(1-\theta_p)(1-\beta\theta_p)(1-\alpha)}{\Gamma\left[1+\alpha(\theta-1)\right]}$$

with $\Gamma \equiv (\theta_p + \omega(1-\theta_p(1-\beta))$.

Following the derivations in Caputo (2003), we obtain a hybrid output-gap equation from utility maximization under habit formation in consumption and application of equilibrium condition $\widehat{c}_t = \widehat{y}_t$. The resulting IS-curve is:

$$\widehat{y}_t = \Psi\beta E_t\left[\widehat{y}_{t+1}\right] + \Psi\widehat{y}_{t-1} - \Omega\left(r_t - E_t\left[\Delta p_{t+1}\right] - rr_t^0\right) + g_t' \quad (25)$$

[15] An empirical justification for including lagged inflation rates is given by Fuhrer and Moore (1995).

where γ is a constant rate-of-risk-aversion (CRRA) parameter, indicating the importance of habit formation in the utility function: $U(C_t, H_t) \equiv \frac{\left(C_t H_t^{-\gamma}\right)^{(1-\sigma)}}{(1-\sigma)}$, with H_t an accustomed aspiration level which depends on past consumption so that it allows for habit formation in consumption (see Caputo (2003)), and

$$\Psi \equiv \frac{\gamma(\sigma - 1)}{\sigma + \gamma\beta(\gamma(\sigma - 1) - 1)}$$
$$\Omega \equiv \frac{1 - \gamma\beta}{\sigma + \gamma\beta(\gamma(\sigma - 1) - 1)}$$

As in the above subsection, the optimal monetary policy reduces to a sequence of static problems in the first stage. In fact, the central bank's problem, at a generic time T, can be solved by minimizing the following Lagrangian in this first stage (again using the law of iterated expectations):

$$\Gamma_T \; : \; = L_T + \sum_{i=0}^{\infty} \delta^i \lambda_{T+i} \left\{ \beta_1 E_T \left[\Delta p_{T+1+i}\right] + \beta_2 \left[\Delta p_{T-1+i}\right] + \gamma \widehat{y}_{T+i} + \upsilon_{T+i} + \right.$$
$$\left. - \Delta p_{T+i} \right\}.$$

The first order conditions turn out to be:

$$\text{-}\ \frac{\partial \Gamma_T}{\partial \Delta p_T} = \Delta p_T - \lambda_T + \delta\beta_2\lambda_{T+1} = 0 \quad ; \tag{26}$$
$$\text{-}\ \text{for } i = \{1, 2, 3, ...\} :$$
$$\frac{\partial \Gamma_T}{\partial \Delta p_{T+i}} = E_T \left[\delta(\Delta p_{T+i} - \lambda_{T+i}) + \delta^2\beta_2\lambda_{T+1+i} + \beta_1\lambda_{T-1+i}\right] = 0 \; ; \tag{27}$$
$$\text{-}\ \text{for } i = \{0, 1, 2, ...\} :$$
$$\frac{\partial \Gamma_T}{\partial \widehat{y}_{T+i}} = E_T \left[b\widehat{y}_{T+i} + \gamma\lambda_{T+i}\right] = 0 \quad . \tag{28}$$

The discretionary policy can be obtained by considering that the central bank uses equations (26) and (28) in period T and then plans to use equations (27) and (28) in the other periods ($t > T$),[16] but optimal policies derived in such a way are (again) dynamically inconsistent since for each current period it is always optimal for the central bank to use (26) instead of (27).

A different and dynamically consistent concept, proposed by e.g. Clarida *et al.* ((1999), p. 1692), is the following.[17] The central bank recognizes at period T that in the future ($t > T$) it will behave just as it does during period T. Therefore, minimizing its (expected) loss the central bank considers $\rho_1 \Delta p_t$ instead of $E_t \left[\Delta p_{t+1}\right]$ in the NKPC (2), where ρ_1 is a parameter of the equilibrium-solution expression: $\Delta p_t = \rho_1 \Delta p_{t-1} + \rho_2 \varsigma_t$.with the white noise

[16] By solving the described problem the optimal condition is found to be $\Delta p_t = -\frac{b}{\gamma}\left(\widehat{y}_t - \beta_2\delta E_t\left[\widehat{y}_{t+1}\right]\right)$.

[17] See also McCallum and Nelson (2000) and Jensen (2002).

error term ς_t By solving we achieve the following optimal general condition for monetary policy in the discretionary regime:

$$\Delta p_t^D = -\frac{b}{\gamma}\left[\left(1-\beta_1\rho_1\right)\widehat{y}_t - \beta_2\delta E_t\left[\widehat{y}_{t+1}\right]\right] \tag{29}$$

By contrast, according to the timeless perspective, optimal monetary policy under the commitment regime must satisfy the following condition derived from equations (27) and (28):

$$\Delta p_t^C = -\frac{b}{\gamma}\left(\widehat{y}_t - \frac{\beta_1}{\delta}\widehat{y}_{t-1} - \beta_2\delta E_t\left[\widehat{y}_{t+1}\right]\right) \tag{30}$$

By using equations (29) and (30) together with IS relation (1), we can derive both optimal output gap and inflation targets and the interest rate reaction function as in the previous subsection. However, the explicit algebraic solutions of those kinds of dynamic systems are rather difficult to obtain[18], and therefore, we limit our attention to the optimality conditions for price dynamics, i.e. equations (29) and (30).

2.4 A hybrid open-economy setup

For our propose it is intereresting to explicitly investigate the impact of the open economy on monetary policy. In this section we analyze the effects of introducing exchange rate channels of monetary policy in the closed-economy framework of the previous subsection.

A simple small open-economy framework is obtained by augmenting the hybrid equations (1) and (2) with the effects of the real exchange rate (see, e.g., Svensson (2000)). In addition, the Uncovered Interest rate Parity (UIP) hypothesis is considered as the rule that governs the flows of capital among the open economies. The hybrid open-economy model becomes:

$$\begin{aligned} \widehat{y}_t &= \pi_1 E_t\left[\widehat{y}_{t+1}\right] + \pi_2\widehat{y}_{t-1} - \alpha(r_t - E_t\left[\Delta p_{t+1}\right] - rr_t^0) \quad (31)\\ &\quad +\zeta x_t + u_t \\ \Delta p_t &= \beta_1 E_t\left[\Delta p_{t+1}\right] + \beta_2\Delta p_{t-1} + \gamma\widehat{y}_t + \eta x_t + v_t \quad (32)\\ r_t - E_t\left[\Delta p_{t+1}\right] &= E_t[x_{t+1}] - x_t + \varrho_t \quad (33)\end{aligned}$$

where $x_t \equiv e_t + p_t^* - p_t$ is the (logarithmic) real exchange rate and ϱ_t is an exogenous noise term reflecting the sum of the real world interest rate, $r_t^* - E_t\left[\Delta p_{t+1}^*\right]$, and a risk premium.[19] e_t *is the logarithmic nominal exchange rate denoting the price of one unit of foreign currency in terms of the domestic currency,* p_t^* *the logarithmic foreign*

[18] Usually, numerical simulations are used; see, e.g., McCallum and Nelson (2000) and Jensen (2002).

[19] Notice that

price level and p_t the logarithmic price level of domestically produced goods. Equation (31) is the simple extension of equation (1) to an open economy. As for the closed-economy case, it nests the open-economy demand obtained by the log-linear approximation to the Euler conditions for the optimal consumption path. The real exchange rate appears because it determines the relative cost of foreign and domestic goods. Equation (32) is a hybrid open-economy NKPC based on staggered price setting, while equation (33) is a real UIP condition that relates the domestic real interest rate to the foreign real interest rate, the rate of real exchange rate depreciation and a risk premium.

The extent to which exchange rate changes are eventually reflected in import prices is commonly referred to as the degree of exchange rate 'pass-through'. Imported goods are made up of a heterogeneous range of commodities and the pass-through may vary considerably across these different types of imports e.g. a (much) higher degree of pass-through for more homogeneous and widely-traded goods (as oil and raw materials), where the so-called 'law of one price' might hold, than for highly differentiated goods. It should be stressed that incomplete pass-through renders the analysis of monetary policy of an open economy fundamentally different from the one of a closed economy, unlike (canonical) models with perfect pass-through which emphasize a type of isomorphism.

According to Caputo (2003), the NKPC satisfies:

$$\Delta p_t = (1-\varphi)[\beta E\left[\Delta p_{t+1}\right] + k(\phi y_t + \vartheta x_t)] + \varphi \Delta p_{t-1} + v'_t \tag{34}$$

where

$$k \equiv \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p(1+\phi\theta_h)}$$

with θ_h the elasticty of demand for domestic output (see (57) of the Appendix) , while the hybrid open-economy IS curve is given by (see (25)):

$$\widehat{y}_t = (1-\vartheta)E_t\{\Psi\beta\left[\widehat{y}_{t+1}\right] + \Psi\widehat{y}_{t-1} - \Omega\left(r_t - E_t\left[\Delta p_{t+1}\right] - rr^0_t\right)\} + \vartheta y^*_t + \zeta x_t + g'_t \tag{35}$$

where x_t is the real exchange rate, ϑ is the degree of openness (share of consumption allocated to imported goods).and

$$\zeta \equiv \frac{\vartheta(\eta^* + \eta - \vartheta\eta)}{1-\vartheta}$$

with η^* and η the foreign and domestic elasticities of substitution between domestic and foreign goods.[20] Interpreting (35) we observe that the output gap

[20] See CES-aggregates (49) and (50) of the Appendix for domestic and foreign consumption, respectively. If an economy has a non-diversifed export sector (i.e. faces a high η^*), the impact of the exchange rate fluctuations will be exacerbated (Caputo (2003)).

in an open economy depends on its domestic expectation, the persistence in this domestic consumption (output gap), the long-term real interest rate, the real exchange rate, and the foreign real output. Furthermore, foreign consumption (output gap) also plays a crucial role, which depends on the degree of habit formation both domestically and abroad.

In studying the optimal program under commitment relative to discretion we again show that the former entails a smoothing of the deviations from the law of one price.[21]

The discretionary optimization problem can be solved now as follows. First, in order to eliminate the nominal interest rate, we substitute the uncovered interest rate parity condition (33) in equation (31), and we solve for the real exchange rate:

$$x_t = \frac{\pi_1 E_t\left[\widehat{y}_{t+1}\right] + \pi_2 \widehat{y}_{t-1} - \alpha(E_t[x_{t+1}] + \varrho_t - E_t\left[\Delta p_{t+1}\right] - rr_t^0) - \widehat{y}_t + u_t}{(1+\eta)} \tag{36}$$

Substituting expression (36) in the open-economy NKPC (32) we obtain:

$$\begin{aligned} \Delta p_t \quad = \quad & \left(\beta_1 + \frac{a\eta}{1+\eta}\right) E_t\left[\Delta p_{t+1}\right] + \beta_2 \Delta p_{t-1} + \left(\gamma - \frac{\eta}{1+\eta}\right)\widehat{y}_t + \\ & + \frac{\eta\left[\pi_1 E_t\left[\widehat{y}_{t+1}\right] + \pi_2 \widehat{y}_{t-1} - \alpha(E_t[x_{t+1}] + \varrho_t - rr_t^0) + u_t\right]}{1+\eta} + v_t \end{aligned} \tag{37}$$

which can be used to find the optimal general condition for discretionary monetary policy:

$$\Delta p_t^D = -\frac{b}{\gamma - \eta\,(1+\eta)^{-1}}\left[\left(1 - \beta_1\rho_1 - \frac{a\eta\rho_1}{1+\eta}\right)\widehat{y}_t - \beta_2 \delta E_t[\widehat{y}_{t+1}]\right] \tag{38}$$

Recall that under a discretionary regime, in which the central bank optimizes each period and is unconstrained by its previous choices, expectations about future outcomes are not affected by the current policy choice.

By contrast, according to the timeless perspective, optimal monetary policy under the commitment regime must satisfy the following condition:

$$\Delta p_t^C = -\frac{b}{\gamma - \eta\,(1+\eta)^{-1}}\left(\widehat{y}_t - \frac{1}{\delta}\left(1 - \beta_1\rho_1 - \frac{a\eta\rho_1}{1+\eta}\right)\widehat{y}_{t-1} - \beta_2 \delta E_t[\widehat{y}_{t+1}]\right) \tag{39}$$

Again, by using equations (38) and (39) together with IS equation (31), we can derive both optimal output-gap and inflation targets and the interest rate

[21] Which is -it should be said again- is in stark contrast with the established empirical evidence. In addition, an optimal commitment policy always requires, relative to discretion, more stable nominal and real exchange rates.

reaction function, but, for computational reasons, a closed-form expression can no longer be obtained so that we limit our attention to the optimal conditions for price dynamics, i.e. equations (38) and (39).

3 Estimations of the NKPC model for the accession countries

In this section we present estimates of the relationships discussed in the theoretical part for different EU-accession countries.

3.1 Data and methodology

It is widely known that the quality of the available data for the CEECs is limited, especially of those data from early in the transition phase. E.g., the decline in output is believed to be overestimated, because newly emerging activities were inadequately captured and existing firms had an incentive to underreport output and sales to avoid taxes (see e.g. Falcetti *et al.* (2002)). Moreover experiences in transition countries have been so different to date that it is questionable that one parameter set would fit the data of all countries equally well. We therefore present estimates country by country. We use quarterly data covering sample periods from the early 1990s until the end of 2002. Inflation is measured as the quarterly logarithmic change in the producer price index. Both the output gaps and the deviation of the interest rates from their steady-state values are approximated by removing a deterministic polynomial time trend from the corresponding level variables. Data are drawn from the IMF's International Financial Statistics database and from the OECD's Statistical Compendium. Clearly, because of the limited time period since the start of transition, and, consequently, because of the fairly limited number of observations, results should be interpreted with caution. Figure 1 plots GDP inflation (solid line, left-hand scale) and the output gap (dashed line, right-hand scale). As to be expected, it is not obvious to infer a close relationship from the graph (compare with figure 3 in Galí *et al.* (2001) for OECD countries). In most countries some correspondences can be detected, however.

At the core of the theoretical framework behind the different versions of the NKPC lies its forward-looking nature. In order to be able to estimate the different versions of the NKPC, we need (conditional) expectations of future inflation. Ideally, one would like to use survey data, where time series on inflation expectations have been collected. Unfortunately we do not have them, and, therefore, conditional expectations have to be formed based on the data set at hand. A possible empirical approach is to use some form of Generalized Method of Moments (GMM) method with linear rational expectations (LREs). Assuming no inflation bias and that $\Delta p_t - \beta_1 E_t [\Delta p_{t+1}] - \beta_2 \Delta p_{t-1} - \gamma \widehat{y}_t$ is orthogonal to a set of variables, collected in the information set of the agents at

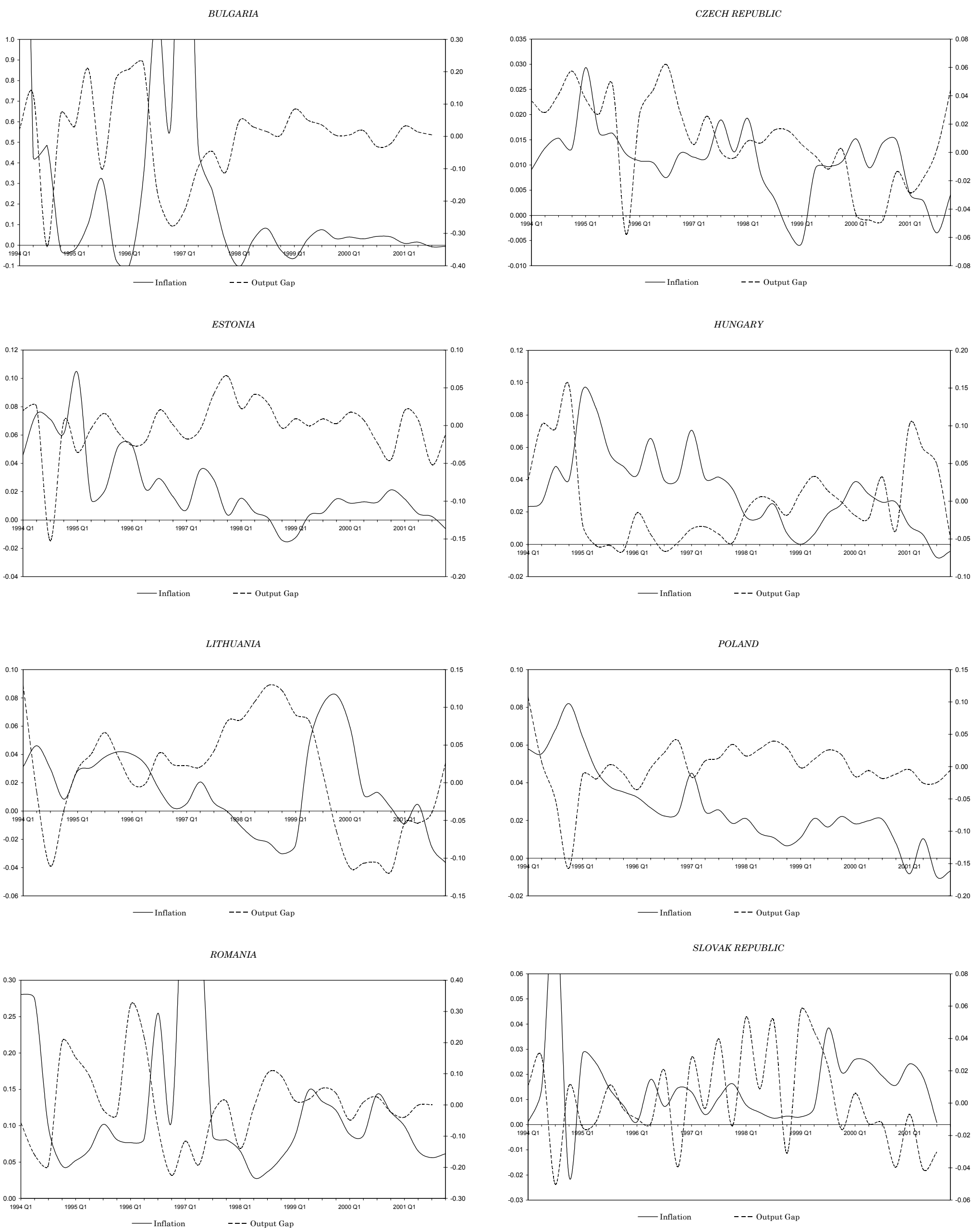

Figure 1: Inflation rates (LHS) and output gaps (RHS) in eight EU-accession countries during 1994-2002

time t, the hybrid NKPC can be identified. Let z_{1t} denote a vector of instruments observed at time t. Then, under LREs, the following set of orthogonality conditions is assumed for the NKPC (2):

$$E_t \left[\left(\Delta p_t - \beta_1 E_t \left[\Delta p_{t+1} \right] - \beta_2 \Delta p_{t-1} - \gamma \widehat{y}_t \right) \ z_{1t} \right] = 0 \tag{40}$$

Likewise, it is possible to define a set of orthogonality conditions for the (hybrid) output-gap equation (1):

$$E_t [(\widehat{y}_t - \pi_1 E_t \left[\widehat{y}_{t+1} \right] - \pi_2 \widehat{y}_{t-1} + \alpha (\widehat{r}_t - E_t \left[\Delta p_{t+1} \right])) \ z_{2t}] = 0 \tag{41}$$

with $\widehat{r}_t \equiv r_t - rr_t^0$.

Rewriting the above orthogonality conditions in vector form:

$$\mathbf{h} \left(\boldsymbol{\theta}, \mathbf{w}_t \right) \equiv \left[\begin{array}{c} E_t \left[\left(\Delta p_t - f_1 \left(\boldsymbol{\theta}, \mathbf{x}_t \right) \right) \right] \ \mathbf{z}_t = 0 \\ E_t \left[\left(\widehat{y}_t - f_2 \left(\boldsymbol{\theta}, \mathbf{x}_t \right) \right) \right] \ \mathbf{z}_t = 0 \end{array} \right] \tag{42}$$

where $\boldsymbol{\theta}$ is the vector of parameters to be estimated, $\boldsymbol{\theta} \equiv [\boldsymbol{\theta}_1 = (\beta_1, \beta_2, \gamma)'$, $\boldsymbol{\theta}_2 = \pi_1, \pi_2, \alpha)']'$ and $\mathbf{w}_t \equiv [\mathbf{v}_t', \mathbf{x}_t', \mathbf{z}_t']'$; $\mathbf{v}_t \equiv [\Delta p_t, \widehat{y}_t]'$; $\mathbf{x}_t \equiv [\mathbf{x}_{1t} = (\Delta p_{t+1}, \Delta p_{t-1}, \widehat{y}_t)'$, $\mathbf{x}_{2t} = (\widehat{y}_{t+1}, \widehat{y}_{t-1}, \widehat{r}_t - \Delta p_{t+1})']'$, $\mathbf{z}_t$ is a vector with instruments $[\Delta p_{t-2}, \Delta p_{t-3}, \Delta p_{t-4}$, $\widehat{y}_{t-2}, \widehat{y}_{t-3}, \widehat{y}_{t-4}$, $\widehat{r}_{t-1}$, $\widehat{r}_{t-2}]'$, it is possible to estimate the model by using GMM. The agents' information set at time t thus consists of three lags of inflation (lags two to four), three lags of de-trended output (lags two to four) and two lags of $\widehat{r}_t$. In small samples GMM estimators are often found to be biased, widely dispersed, sensitive to the normalization of the orthogonality conditions and to the choice of the instrument set. In order to minimize the potential estimation bias that is known to arise in small samples with too many overidentifying restrictions, we opt for a relatively small number of lags for the instruments. The two-step GMM estimator used here is known to be less sensitive to these small-sample biases.[22] To control for serial correlation in the error term, the standard errors presented in the tables are modified using a Newey-West correction. Since sample sizes are fairly limited and the period covered is one of drastic changes, GMM results should be interpreted with caution.

Since the occurrence of the output gap in closed-economy NKPCs is quite debated in empirical contributions (see Galí and Gertler (1999), Galí *et al.* (2001), Gertler *et al.* (2001), Jondeau and Le Bihan (2001), Leith and Malley (2002), and Sbordone (2002)), and since also in our estimations its effects were not so conclusive, we estimated the (hybrid) NKPC (7) using the logarithmic deviation of the real unit labour cost (or, equivalently, the labour income share) from its mean as a measure for the deviation of the real marginal cost from its steady-state level (see also (9) under a Cobb-Douglas production function). This variable has a better empirical record in the literature on inflation dynamics in the Euro-area and the US (see e.g. Jondeau and Le Bihan (2001)). Real unit

[22] See e.g. the July 1996 special issue of the *Journal of Business and Economics Statistics.*

Figure 2: Inflation rates (LHS) and demeaned real unit labour costs (RHS) in eight EU-accession countries during 1994-2002

labour costs are constructed as the logarithmic ratio of (quarterly) compensation per employee times employment and GDP ($w+n-y$). Figure 2 plots this variable against the inflation rate in the different countries. Again it is not possible to infer a close relationship from this figure. Then, the agents' information set is extended with two lags of marginal costs $\widehat{mc}_{t-1}$ and $\widehat{mc}_{t-2}$.

3.2 The purely forward-looking closed-economy model

By setting $\beta_2 = \pi_2 = 0$ in (1) and (2), respectively, we obtain the purely forward-looking closed-economy model. The remaining parameters β_1, π_1, γ and α are convolutions of structural or deep parameters from the microeconomic theory behind the New Keynesian model. As a consequence of the joint optimal price and output-gap setting, specification ((3)-(4)) provides some immunity with respect to the Lucas critique. Parameters to be estimated are structural ones, so that they are not likely to change as the policy regime varies. GMM estimation under cross equation restrictions is performed for the above mentioned output-gap version and for the marginal cost (gap) version of the closed-economy NKPC (7).

Table 1 shows the results for the purely forward-looking closed-economy case described in ((6)-(7)) using the Leontief and the Cobb-Douglas production functions.The identifying assumptions used are $\theta_p = 0.75$ (i.e. prices are on average fixed for four quarters), $\alpha = 0.4$ and $\theta = 11$, implying a desired markup of 1.1. An apparent fact is that the estimated private sector discount factor β is very high and even larger than 1 in some cases. Using the Cobb-Douglas production function βs are generally higher and nowhere significantly smaller than one. σ, the relative risk aversion parameter of households, varies between 5.7 and 16.3. Overidentifying restrictions are rejected in all cases by the J-statistic.

3.3 The hybrid closed-economy models

The hybrid model adds backward-looking behavior to the forward-looking elements in the previous subsection. According to the hybrid model of Clarida *et al.* (1999) the parameters of equations (22) and (23) can be estimated according to GMM as in Tables 2 and 3.

With the exception of Latvia, this *ad hoc* model performs quite well. In most cases the estimated discount factor is smaller than one, especially in the Cobb-Douglas case. Leaving aside Latvia, we observe in the tables that the proportion or degree of forward-looking firm behavior in the NKPC (23) ranges from 0.42 (Hungary) to 0.80 (Slovak Republic) for the Leontief production function, so that the degree of forward-lookingness of firms strongly varies among CEECs. The Cobb-Douglas case also shows a dispersion across countries and the point estimates strongly differ (lowest is now Lithuania (0.44) and highest Romania (0.79). In a similar study, Gerberding (2001, p.23) argues that the

	Leontief			Cobb-Douglas		
	β	σ	J-stat	β	σ	J-stat
Bulgaria	0.8795	7.4234	5.0103	0.8828	7.3781	5.0485
	(0.1203)	(1.0881)	(0.93)	(0.1217)	(1.1054)	(0.92)
Czech Republic	1.0229	11.3144	7.0626	0.9728	10.9254	7.1774
	(0.0546)	(4.4494)	(0.79)	(0.0584)	(4.2326)	(0.78)
Estonia	0.9397	7.6085	8.7676	1.0951	7.8415	7.3928
	(0.0574)	(1.6301)	(0.64)	(0.0881)	(2.0040)	(0.76)
Hungary	0.9938	8.3705	6.7701	0.9936	15.1696	6.4248
	(0.0349)	(3.5157)	(0.82)	(0.0342)	(17.0781)	(0.84)
Latvia	0.6954	6.0889	7.4514	1.2396	8.3825	7.6756
	(0.0925)	(1.2328)	(0.76)	(0.0873)	(2.5729)	(0.74)
Lithuania	0.9449	7.2536	8.6041	1.5197	16.3187	8.6840
	(0.0440)	(1.2978)	(0.66)	(0.1407)	(3.1160)	(0.65)
Poland	1.2177	11.7596	9.8140	1.3027	16.3252	8.8358
	(0.0315)	(4.2482)	(0.54)	(0.0132)	(7.9799)	(0.64)
Romania	1.0536	5.4828	7.4484	1.1071	10.4041	7.9370
	(0.0392)	(1.1748)	(0.76)	(0.0401)	(5.7370)	(0.72)
Slovak Republic	0.9317	5.1375	7.3521	1.0414	5.6871	6.6820
	(0.0887)	(2.4764)	(0.77)	(0.0853)	(2.5938)	(0.82)
Slovenia	1.0298	10.6713	7.8293	1.2079	14.0415	9.0746
	(0.0361)	(2.1390)	(0.73)	(0.0192)	(3.3071)	(0.61)

Table 1: GMM estimates for the purely forward-looking closed-economy model using demeaned marginal costs in the NKPC - Leontief vs Cobb-Douglas production function (Newey-West standard errors between parentheses)

	β	σ	χ	φ	J-stat
Bulgaria	0.8102	2.1332	0.3733	0.6309	6.5261
	(0.1999)	(0.2572)	(0.1832)	(0.1047)	(0.84)
Czech Republic	1.0251	2.7197	0.7976	0.4634	8.6618
	(0.0583)	(0.6706)	(0.2944)	(0.0628)	(0.65)
Estonia	1.0750	2.3533	0.2802	0.5477	6.8290
	(0.1158)	(0.4553)	(0.1236)	(0.1340)	(0.81)
Hungary	0.9765	2.4123	0.2879	0.4205	7.6753
	(0.0803)	(0.4641)	(0.1555)	(0.0974)	(0.74)
Latvia	0.2133	8.0612	0.3119	0.2652	8.4648
	(0.2005)	(2.6919)	(0.1130)	(0.0833)	(0.67)
Lithuania	0.9633	10.8965	0.6057	0.3911	9.0468
	(0.1557)	(1.6859)	(0.0878)	(0.0704)	(0.62)
Poland	1.1093	2.6466	0.4288	0.7319	10.4797
	(0.0331)	(0.6079)	(0.1136)	(0.1241)	(0.49)
Romania	1.0300	2.0724	0.6608	0.7807	6.5396
	(0.0613)	(0.3014)	(0.0673)	(0.0510)	(0.83)
Slovak Republic	1.0811	10.9054	0.1950	0.8047	7.4210
	(0.0690)	(26.7033)	(0.1782)	(0.1350)	(0.76)
Slovenia	1.0038	2.7835	0.5845	0.7433	9.6451
	(0.0332)	(0.4924)	(0.2192)	(0.0249)	(0.55)

Table 2: GMM estimates for the hybrid closed-economy model, based on Clarida et al. (1999), Leontief production function (Newey-West standard errors between parentheses)

	β	σ	χ	φ	J-stat
Bulgaria	0.7246	8.7410	0.3299	0.6403	5.1542
	(0.1403)	(1.9781)	(0.1299)	(0.1598)	(0.90)
Czech Republic	0.9864	5.7752	0.7188	0.4645	8.7316
	(0.0835)	(2.2860)	(0.2202)	(0.0654)	(0.65)
Estonia	1.0441	11.1729	0.3783	0.4568	5.4120
	(0.1206)	(6.0773)	(0.1309)	(0.1157)	(.88)
Hungary	0.8933	6.6812	0.3839	0.5505	8.7915
	(0.0725)	(2.5016)	(0.1672)	(0.1120)	(0.64)
Latvia	0.8766	12.4471	0.5748	1.1191	12.5311
	(0.1013)	(4.0165)	(0.0419)	(0.1926)	(0.32)
Lithuania	0.6562	13.8643	0.6007	0.4392	8.2466
	(0.0660)	(2.8123)	(0.0402)	(0.0592)	(0.69)
Poland	0.8787	12.7997	0.5823	0.5990	7.9952
	(0.1268)	(3.8143)	(0.1316)	(0.1869)	(0.71)
Romania	0.9649	10.9377	0.6494	0.7852	6.5103
	(0.0582)	(3.7352)	(0.0624)	(0.0458)	(0.84)
Slovak Republic	1.0055	5.6686	0.2660	0.5848	7.7765
	(0.1086)	(2.8735)	(0.1860)	(0.1442)	(0.73)
Slovenia	0.9825	22.7463	0.6666	0.7213	11.4503
	(0.0348)	(5.0729)	(0.0497)	(0.0217)	(0.40)

Table 3: GMM estimates for the hybrid closed-economy model based on Clarida et al. (1999) - Cobb-Douglas production function (Newey-West standard errors between parentheses)

estimated degree of forward-lookingness in a German Phillips curve is higher than in an Italian Phillips curve as German monetary policy was more credible. If this argument carries over to transition countries, we observe that the Slovak Republic, Romania, Slovenia, and Poland have shown a more credible monetary policy than the other CEECs considered. By contrast, Lithuania, Hungary, and the Czech Rebublic seemed to perform (significantly) worse in terms of past credibility as far as a Leontief production function is appropriate. Under a Cobb-Douglas technology, Hungary shows a more credible monetary policy. Of course, results have to be interpreted with caution since Gerberding's argument might not be valid for transition economies, e.g. because of different liberalization degrees in the sample period.

Results of Tables 2 and 3 are roughly in the same direction as the recent estimations for NKPCs in the United States that are reported in Table X.

Table X – Estimates of NKPCs for the United States

		Per/Meth
Linde (2002)	$\Delta p_t = 0.46 E_t \Delta p_{t+1} + 0.72 \Delta p_{t-1} + 0.03 \widehat{y}_t + \widetilde{\nu}_t$ $\Delta p_t = 0.28 E_t \Delta p_{t+1} + 0.72 \Delta p_{t-1} + 0.05 \widehat{mc}_t + \widetilde{\nu}_t$	1960-97/ML
Söderlind et al. (2002)	$\Delta p_t = 0.1 E_{t-1} \Delta p_{t+3} + 0.9[0.67 \Delta p_{t-1} - 0.14 \Delta p_{t-2} +$ $+ 0.04 \Delta p_{t-3} - 0.07 \Delta p_{t-4}] + 0.13 \widehat{y}_{t-1} + \widetilde{\nu}_t$	1987-99/calibration based on matching moments
Domenech et al. (2001)	$\Delta p_t = 0.54 E_t \Delta p_{t+1} + 0.46 \Delta p_{t-1} + 0.06 \widehat{y}_{t-1} + \widetilde{\nu}_t$	1986-00/GMM
Jondeau and Le Bihan (2001)	$\Delta p_t = 0.53 E_t \Delta p_{t+1} + 0.47 \Delta p_{t-1} + 0.001 + \widetilde{\nu}_t$ $\Delta p_t = 0.54 E_t \Delta p_{t+1} + 0.46 \Delta p_{t-1} + 0.06 \widehat{mc}_t + \widetilde{\nu}_t$	1970-99/ML
Galí et al. (2001)	$\Delta p_t = 0.36 E_t \Delta p_{t+1} + 0.60 \Delta p_{t-1} + 0.02 \widehat{mc}_t + \widetilde{\nu}_t$	1960-94/GMM
Ruud and Whelan (2001)	$\Delta p_t = 0.61 E_t \Delta p_{t+1} + 0.39 \Delta p_{t-1} + \widetilde{\nu}_t$	1960-97/GMM
Rudebusch (2002)	$\Delta p_t = 0.29 E_t \Delta p_{t+1} + 0.71 \Delta p_{t-1} + 0.13 \widehat{y}_t + \widetilde{\nu}_t$	1968-96/OLS
Galí and Gertler (1999)	$\Delta p_t = 0.68 E_t \Delta p_{t+1} + 0.25 \Delta p_{t-1} + 0.04 \widehat{mc}_t + \widetilde{\nu}_t$	1960-94/GMM

Table 4 shows the results of NKPC (24). The proportion ω of backward looking firms seems in line with the parameters estimated in the *ad hoc* hybrid model above. The estimated discount factor is now smaller than one in almost all countries, though not always statistically signifcant below 1.

3.4 The hybrid open-economy New Keynesian model

GMM estimations of (35) and (34) are presented in table 5. Following Caputo (2003) additional identifying assumptions have been made as follows: $\eta = \eta^* = 1.5$; $\gamma = 0.8$ and $\sigma = 7.5$.

4 Concluding remarks

This paper studies different implications of alternative monetary policy regimes for small open economies as the EU-accession countries from Central and Eastern Europe, both from a theoretical and an empirical point of view.

	β	ω	γ	J-stat
Bulgaria	0.6017	0.3775	0.5620	6.6586
	(0.0977)	(0.2000)	(0.0704)	(0.83)
Czech Republic	0.5701	0.8753	0.7741	9.1612
	(0.2698)	(0.0714)	(0.1638)	(0.61)
Estonia	0.7211	0.6785	0.7902	5.9258
	(0.1454)	(0.1595)	(0.2196)	(0.88)
Hungary	0.9047	0.5244	0.9117	9.5328
	(0.0761)	(0.1565)	(0.1045)	(0.57)
Latvia	0.8635	0.4608	0.6717	9.0124
	(0.2307)	(0.1934)	(0.0733)	(0.62)
Lithuania	-	-	-	-
	(-)	(-)	(-)	(-)
Poland	0.8738	0.4720	0.6256	7.6826
	(0.0968)	(0.1269)	(0.2138)	(0.74)
Romania	1.2012	0.1951	0.6212	6.8506
	(0.1150)	(0.1066)	(0.1096)	(0.81)
Slovak Republic	0.8233	0.8428	0.2284	8.1835
	(0.2551)	(0.4055)	(0.0626)	(0.70)
Slovenia	0.9929	0.5391	0.9220	6.2133
	(0.0891)	(0.2775)	(0.1372)	(0.86)

Table 4: GMM estimates for the hybrid closed-economy model, based on Gali et al. (2001) and Caputo (2003) (Newey-West standard errors between parentheses)

	β	ϑ	φ	J-stat
Bulgaria	0.6727	0.6039	0.5888	9.0184
	(0.1720)	(0.0240)	(0.0664)	(0.62)
Czech Republic	0.9208	0.0179	0.2385	9.2072
	(0.0488)	(0.0052)	(0.0578)	(0.59)
Estonia	0.8373	0.0182	0.4099	8.1827
	(0.0796)	(0.0047)	(0.0495)	(0.70)
Hungary	0.8850	0.0150	0.6023	8.7152
	(0.4804)	(0.0061)	(0.1249)	(0.65)
Latvia	0.8149	0.0205	0.3191	8.5966
	(0.0990)	(0.0040)	(0.0664)	(0.66)
Lithuania	1.4331	0.0008	0.5923	9.4927
	(0.0604)	(0.0003)	(0.0431)	(0.58)
Poland	1.1312	0.0094	0.4307	10.3966
	(0.0619)	(0.0023)	(0.0833)	(0.49)
Romania	0.8672	0.1374	0.3681	8.0098
	(0.1426)	(0.0435)	(0.0676)	(0.71)
Slovak Republic	0.7808	0.1246	0.2986	9.8595
	(0.2428)	(0.0377)	(0.1099)	(0.54)
Slovenia	1.0118	0.0047	0.4829	8.9900
	(0.0494)	(0.0014)	(0.0515)	(0.62)

Table 5: GMM estimates for the open-economy New Keynesian model (Newey-West standard errors between parentheses)

From a theoretical point of view, we studied dynamic versions of output gap and inflation equations based on direct generalizations of the standard closed economy New Keynesian model with sticky (nominal) prices as described in Galí *et al.* (1999). The derivations of hybrid output gaps and inflation dynamics are presented as well in a closed-economy framework as in an open-economy one and implications of alternative monetary policy regimes as policy rules under discretion and commitment are discussed in such settings, where both forward- and backward-looking expectations are allowed.

From an empirical point of view, we consider each of the EU-accession CEECs as a small open economy being largely dependent on external shocks in an extended micro-founded New Keynesian setup. Our empirical estimations for the accession countries suggest that during the transition phase, both forward- and backward-looking inflation expectations did significantly matter in these countries. Under a Leontief technology we observe that the proportion or degree of forward-looking firm behavior in the New Keynesian Phillips Curve ranges from 0.42 (Hungary) to 0.80 (Slovak Republic), so that the degree of forward-lookingness of firms strongly varies among CEECs. The Cobb-Douglas case also shows a dispersion across countries but the point estimates strongly differ (lowest is now Lithuania (0.44) and highest Romania (0.79). In a similar study, Gerberding (2001, p.23) argues that the estimated degree of forward-lookingness in a German Phillips curve is higher than in an Italian Phillips curve as German monetary policy was more credible. If this argument carries over to transition countries, we observe that the Slovak Republic, Romania, Slovenia, and Poland have shown a more credible monetary policy than the other CEECs considered. By contrast, Lithuania and the Czech Rebublic seemed to perform (significantly) worse in terms of past credibility. Of course, results have to be interpreted with caution since Gerberding's argument might not be valid for transition economies, e.g. because of different liberalization degrees during the sample period (1994-2002).

Appendix: A hybrid version for a New Open-Economy Macroeconomics (NOEM) model

Following Clarida *et al.* (2002), Galí and Monacelli (2002), and Smets and Wouters (2002a) we present a NOEM model in the context of *two open economies under a flexible exchange rate regime*. We assume that there are two countries, a home (h) and a foreign (f) country. Each country is assumed to have an own currency. Given this plurality of currencies, it is necessary to convert all prices into the same currency unit. There is a continuum of households and firms. Households differ in that they consume an own basket of goods and supply a differentiated type of labor. Hence, each household has a monopolistically competitive power over the supply of its labor. This labor, however, is assumed to be internationally immobile, while each country is assumed to be (relatively) specialized in the production of one (index of) good(s), but consumers in any country consume both (indexes of) goods. As a consequence, there is trade between the two countries. There is perfect risk sharing as far as consumers are concerned and saving flows are assumed to be perfectly mobile between the two countries. Within each country, households consume a domestically produced (index of) good(s) and an imported (index of) good(s). Domestic production is assumed to take place in two stages. First, it is assumed that a continuum of intermediate goods firms exist, each producing a differentiated material input. Final goods producers then combine these inputs into output, which they sell to households. Intermediate goods producers are monopolistic competitors who each produce a differentiated product and set nominal prices on a staggered basis. Final goods producers are assumed to be perfectly competitive. Hence, imperfect competition is assumed to exist only on the intermediate goods markets and not on the final goods market, allowing us to introduce rigidities on nominal prices due to staggered, Calvo-style (random-duration) price contracts in these intermediate goods markets.

Describing the *households' problem in open economies*, the domestic household i is assumed to maximize expected utility over its consumption C^i of both domestic and foreign goods and its leisure $(1 - N^i)$, with N^i the domestic household i's working period remunerated at a rate of W^i, according to the intertemporal utility function $E_t \left[\sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[U(C^i_\tau, N^i_\tau) \right] \right]$, where the period utility function $U(C^i_\tau, N^i_\tau)$ is assumed to be concave, differentiable and strongly separable in consumption and leisure.[23] Hence, household i's intertemporal utility

[23] Note that we do not take explicit account of real money balances in this intertemporal utility function; otherwise, households' financial wealth in the form of real cash balances, bonds, stocks, etc. should be modeled explicitly. However, due to the assumed strong separability in the utility function, money balances would not enter in the derived demands for consumption goods and derived supplies of labor services. Financial wealth will be modeled within the framework of the accumulation of total wealth, without explicit reference to the intertemporal utility function.

function can be written as:

$$E_t\left[\sum_{\tau=t}^{\infty}\beta^{\tau-t}\left[U_1(C_\tau^i)-U_2(N_\tau^i))\right]\right] . \tag{43}$$

Each household i is assumed to begin each period τ with a portfolio of claims on firms, holding a previously determined share ω_τ^i of the per capita value of these firms.[24] This portfolio generates current nominal dividends $\omega_\tau^i Z_\tau$ with a market value $DIV_\tau^i \equiv \omega_\tau^i V_\tau$, where V_τ is measured on a pre-dividend basis. Furthermore, each household i is assumed to begin each period τ with a stock of nominal bonds left over from last period which have matured and have market value B_τ^i and with nominal debt D_τ^i arising from consumption (and leisure) purchases last period. Hence, household i's (total) nominal wealth at period τ is $\omega_\tau^i V_\tau + B_\tau^i - T_\tau^i - D_\tau^i$, where T_τ^i are this household's nominal lump-sum taxes paid to the government at period τ. With this nominal wealth and with the current nominal wage income $W_\tau^i N_\tau^i$, household i may purchase goods, bonds,[25] or may buy more claims on firms, each unit of which costs $(V_\tau - Z_\tau)$.

Summarizing, the sequence of intertemporal budget constraints with which a domestic household i is confronted in an open economy can be written as:

$$\begin{aligned} & P_{h,\tau}C_{h,\tau}^i + P_{f,\tau}C_{f,\tau}^i + E_\tau\left[\varphi_{\tau,\tau+1}B_{\tau+1}^i\right] + E_\tau\left[\varphi_{\tau,\tau+1}^* e_{\tau+1}B_{\tau+1}^{*i}\right] + \omega_{\tau+1}^i(V_\tau + V_\tau^* - Z_\tau - Z_\tau^*) \\ \leqq\ & W_\tau^i N_\tau^i + \omega_\tau^i(V_\tau + e_\tau V_\tau^*) + B_\tau^i + e_\tau B_\tau^{*i} - T_\tau^i - D_\tau^i \end{aligned} \tag{44}$$

where $C_{k,\tau}^i$ $(k = h, f)$ are composite indexes of domestic and foreign consumption goods consumed by domestic household i, i.e. $C_{h,\tau}^i$ is the index of household i's consumption goods produced in the home country and $C_{f,\tau}^i$ is the index of household i's consumption goods produced in the foreign country; these indexes are defined as CES-baskets of consumption goods:

$$C_{k,\tau}^i \equiv \left(\int_0^1 C_{k,\tau}^i(z)^{\frac{\theta_k-1}{\theta_k}}dz\right)^{\frac{\theta_k}{\theta_k-1}} , \tag{45}$$

with the intertemporal elasticities of substitution between the differentiated consumption goods given by $\theta_k > 1$ $(k = h, f)$,[26] where $P_{k,\tau}$ $(k = h, f)$ are the correspondingly defined (consumption-based) price indexes, i.e. the price index of the consumption goods produced at home and the price index for the imported consumption goods, respectively; they can be defined as:[27]

[24] See e.g. Kahn *et al.* (2002).

[25] Notice that each household i can hold two types of noncontingent bonds, one denominated in home currency with market value B_τ^i and the other denominated in foreign currency with market value B_τ^{*i}.

[26] As $\theta_k \to \infty$, the (corresponding) product market tends towards a state of perfect competition and the underlying demand function becomes perfectly elastic so that the differentiated consumption goods become perfect substitutes.

[27] We come back to this definition in the treatment of the producers' problem later.

$$P_{h,\tau} \equiv \left(\int_0^1 (P_{h,\tau}(z))^{1-\theta_h} dz \right)^{\frac{1}{1-\theta_h}} \quad \text{and} \quad P_{f,\tau} \equiv e_\tau \left(\int_0^1 (P_{f,\tau}(z))^{1-\theta_f} dz \right)^{\frac{1}{1-\theta_f}}, \tag{46}$$

with e_τ the nominal exchange rate at time τ expressed as the amount of domestic currency for one unit of foreign currency. Furthermore, $\varphi_{\tau,\tau+1}$ ($\varphi^*_{\tau,\tau+1}$) is a stochastic nominal discount factor representing the current value of nominal domestic (foreign) bond income at date $\tau+1$ in any given state at time τ,[28] B^i_τ and B^{*i}_τ represent the holdings of domestic one-period (government) bonds and the holdings of one-period bonds issued by the foreign country in foreign currency.[29] So, we assume that consumers hold a well diversified portfolio of all the firms in the economy, allowing them to eliminate the risks due to e.g. staggered price setting (for the intermediate goods firms that operate in an imperfectly competitive environment).

The second (utility) felicity in (43) reflects (the negative of) domestic consumer i's utility derived from leisure, which is the residual of the individuals' time endowment (with a normalized value of 1) after supplying their labor services to the (domestic) firms. As mentioned before, workers are assumed to be monopolistically competitive suppliers of their labor services N^i_τ.

Maximization of (43) subject to (44) leads to a domestic consumer's Euler equation for consumption that is generally unsolvable for general forms of uncertainty.[30] Therefore, we respecify the intertemporal utility function (43) for a specific period τ as:[31]

$$U_1(C^i_\tau) - U_2(N^i_\tau)) = \frac{e^{\varepsilon_\tau}(C^i_\tau)^{1-\sigma}}{(1-\sigma)} - \frac{e^{\zeta_\tau}(N^i_\tau)^{1+\phi}}{(1+\phi)}, \tag{47}$$

where σ is a parameter of relative risk aversion of domestic households being equal to the inverse of the intertemporal elasticity of substitution of consumption goods, ϕ is the inverse of the intertemporal elasticity of work effort with respect to the real wage, and where e^{ε_τ} and e^{ζ_τ} are appropriately-defined stochastic preference shocks: e^{ε_τ} is the preference shock that affects the intertemporal

[28] Hence, $(1+r_\tau)^{-1} = E_\tau\left[\varphi_{\tau,\tau+1}\right]$ is the price of a riskless one-period domestic nominal bond with r_τ its gross return or the domestic nominal interest rate (discounting factor interpretation). Of course, we also have: $(1+r^*_\tau)^{-1} = E_\tau\left[\varphi^*_{\tau,\tau+1}\right]$, with r^*_τ the foreign nominal interest rate.

[29] Similar reasonings for domestic and foreign firms issuing dividends.

[30] See e.g. Leith and Malley (2002), p. 8.

[31] Note that several consumer problem studies (e.g. Smets and Wouters (2002b)) take explicitly account of time-varying habit formation in the intertemporal utility function, e.g. by considering $\frac{e^{\varepsilon_\tau}(C^i_\tau - H^i_\tau)^{1-\sigma}}{(1-\sigma)}$ as the first felicity in (47), with H^i_τ as domestic consumer i's habit stock, which is in many cases assumed to be proportional to her aggregate past consumption: $H_\tau = h^i_\tau C^i_{\tau-1}$.

substitution of domestic households and e^{ε_τ} represents the stochastic shock to the labor supply.

Maximization of (43) subject to (44), now with (47) as the special period's utility expression, results in the following intratemporal first order conditions:

$$\beta E_\tau \left\{ \frac{e^{\varepsilon_{\tau+1}}}{e^{\varepsilon_\tau}} \left(\frac{C^i_{\tau+1}}{C^i_\tau} \right)^{-\sigma} \frac{P_\tau \left(1 + r_\tau\right)}{P_{\tau+1}} \right\} = 1 \quad \text{and} \quad (C^i_\tau)^\sigma (N^i_\tau)^\phi = \frac{W^i_\tau}{P_\tau} \ , \quad (48)$$

where the first equation in (48) is the domestic household i's Euler equation for consumption and where use has been made of the definition of the aggregate consumption basket of home and foreign (import) goods, which is assumed to satisfy a CES specification:[32]

$$C_\tau \equiv \left[(1-\alpha_c)^{\frac{1}{\eta_c}} C_{h,\tau}^{\frac{\eta_c - 1}{\eta_c}} + \alpha_c^{\frac{1}{\eta_c}} C_{f,\tau}^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}} \quad (49)$$

with η_c the elasticity of substitution between domestic and foreign (consumption) goods ($\eta_c > 0$) and α_c determining the steady-state share of imported goods in total consumption.[33] The aggregate composite price index as a function of the price indexes of the domestically produced consumption goods and the imported consumption goods can directly be derived by minimizing the cost of purchasing one unit of the aggregate composite consumption bundle (49). Hence, the optimal allocation for expenditures between domestic and foreign consumption goods (indexes) satisfies:

$$C_{h,\tau} = (1-\alpha_c) \left(\frac{P_{h,\tau}}{P_\tau} \right)^{-\eta_c} C_\tau \quad (51)$$

and

$$C_{f,\tau}(z) = \alpha_c \left(\frac{P_{f,\tau}}{P_\tau} \right)^{-\eta_c} C_\tau. \quad (52)$$

The cost minimizing demands for domestically and foreignly produced goods in the foreign country are derived in a similar fashion from (50) as:

$$C^*_{h,\tau} = \alpha^*_c \left(\frac{P^*_{h,\tau}}{P^*_\tau} \right)^{-\eta^*_c} C^*_\tau \quad \text{and} \quad C^*_{f,\tau} = (1-\alpha^*_c) \left(\frac{P^*_{f,\tau}}{e_\tau P^*_\tau} \right)^{-\eta^*_c} C^*_\tau \ . \quad (53)$$

[32] See e.g. Galí (2002) and Smets and Wouters (2002).

[33] Hence, C_τ can be viewed as a composite of two (indices of) goods, while, similarly, the composite (index of) good(s) for the foreign consumers is defined as:

$$C^*_\tau \equiv \left[(1-\alpha^*_c)^{\frac{1}{\eta^*_c}} (C^*_{f,\tau})^{\frac{\eta^*_c - 1}{\eta^*_c}} + (\alpha^*_c)^{\frac{1}{\eta^*_c}} (C^*_{h,\tau})^{\frac{\eta^*_c - 1}{\eta^*_c}} \right]^{\frac{\eta^*_c}{\eta^*_c - 1}} \quad (50)$$

where $C^*_{f,\tau}$ is the quantity of the (index of) good(s) produced and consumed in the foreign country at period τ and $C^*_{h,\tau}$ is the quantity of the (index of) good(s) that is consumed in the foreign country during that same period, but which originates from the other (i.e. domestic) country; in other words, $C^*_{h,\tau}$ is the home export of consumption goods in a two-country setting.

Dividing (51) by (52), we get: $\frac{C_{h,\tau}}{C_{f,\tau}} = \frac{(1-\alpha_c)}{\alpha_c} \left(\frac{P_{f,\tau}}{P_{h,\tau}}\right)^{-\eta_c}$ so that, for a normalized aggregate consumption basket ($C_\tau = 1$), the imported consumption goods (index) $C_{f,\tau}$ can be eliminated from (49) and the following CES-aggregate of prices for domestic consumption goods, $P_{h,\tau}$, and foreign consumption goods, $P_{f,\tau}$, or aggregate consumption price, is obtained (see definitions (46)):

$$P_\tau = \left[(1-\alpha_c) P_{h,\tau}^{1-\eta_c} + \alpha_c P_{f,\tau}^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}} . \tag{54}$$

Log-linearizing the domestic household i's Euler equation in (48) we get the following expression, where lower-case letters denote the logarithms of the corresponding variables:

$$\log\beta - \sigma E_\tau \left(c_{\tau+1}^i\right) + \sigma c_\tau^i - E_\tau \left(\Delta p_{\tau+1}\right) + r_\tau = 0,$$

with $E_\tau \left(\Delta p_{\tau+1}\right) \equiv E_\tau \left(p_{\tau+1}\right) - p_\tau$ the expected CPI inflation, or the optimal household i's aggregate consumption satisfies:

$$c_\tau^i = E_\tau \left(c_{\tau+1}^i\right) - \frac{1}{\sigma}\left(r_\tau - E_\tau \left(\Delta p_{\tau+1}\right) + \log\beta\right) \tag{55}$$

The optimal allocation of any given expenditure within each category of goods also yields the demand functions for the domestic and imported composite goods (indexes) from the above optimization and the expressions (45) and (46):[34]

$$C_{h,\tau}(z) = \left(\frac{P_{h,\tau}(z)}{P_{h,\tau}}\right)^{-\theta_h} C_{h,\tau} \qquad \text{and} \qquad C_{f,\tau}(z) = \left(\frac{e_\tau P_{f,\tau}(z)}{P_{f,\tau}}\right)^{-\theta_f} C_{f,\tau}. \tag{57}$$

The *firms' problem in open economies* can be disentangled in two stages: one for final goods (or, alternatively, wholesale goods) and one for intermediate goods (or, alternatively, retail goods). The inspiration for an intermediate goods versus final goods situation can be found in Clarida *et al.* (2002), while that for the wholesale goods versus retail goods situation can be observed in Gilchrist *et al.* (2002). More particularly, final goods firms produce these goods

[34] Analagous to (57) the intermediate-goods production sector could be described by a continuum of monopolistically competitive firms each of which faces a downward-sloping demand curve for its differentiated product:

$$P_{k,\tau}(z) = \left(\frac{C_{k,\tau}(z)}{C_{k,\tau}}\right)^{-1/\theta_k} P_{k,\tau} \qquad \text{for } k = h, f \tag{56}$$

This demand function can also be derived from Dixit-Stiglitz preferences, where $P_{k,\tau}(z)$ is the profit-maximizing price consistent with production level $C_{k,\tau}(z)$.

in competitive markets and use intermediate goods, produced in monopolistically competitive markets, while, alternatively, national entrepreneurs produce wholesale goods in competitive markets and then sell their output to national retailers, who are monopolistic competitors. The latter differentiate the wholesale goods at no resource cost and sell them to households. Given that the intermediate goods producers (or, alternatively, the retailers) are price-setters, this allows us to introduce nominal rigidities. Notice that, indeed, two different situations can be described by this modelling procedure: in the intermediate goods vis-à-vis the final goods situation, the output sellers to consumers operate in perfectly competitive markets, while in the wholesale-retail situation, the output sellers to consumers operate in imperfectly competitive markets. We focus on the first situation where in principle each of the two countries might be assumed to have a continuum of final goods producers and intermediate goods producers. Typically, we may consider a situation where foreign exporting firms sell intermediate goods to domestic firms. Then, these domestic firms assemble the imported intermediate goods and sell final goods to consumers. When domestic firms face significant competition from other domestic final goods producing sectors (as e.g. the non-traded goods sector) it can generally be assumed that they prefer to price in domestic currency, while exporting firms tend to price in the exporter's currency. Hence, domestic firms generally import goods priced in foreign currency and (often) sell them in domestic currency, due to competitive pressure in the domestic market, even though they are subject to exchange rate risk. In such a case the exchange rate pass-through to import prices (producer currency pricing) is incomplete, while the pass-through to consumer (or local currency) prices is zero (or very limited); in general, the (degree or intensity of) pass-through of exchange rates to consumer prices is much lower than the pass-through to import prices.[35]

We assume that there is a fraction s of firms (indexed by $z = 0, ..., s$) that exhibit consumer currency pricing by setting prices in the local currency and that the remaining fraction $(1-s)$ of firms (indexed by $z = s, ..., 1$) exhibit producer currency pricing, i.e. they set the price of goods in their own currency. Hence, the definition (46) of aggregate price indexes is changed into:

$$P_{h,\tau} \equiv \left(\int_0^s (P_{h,\tau}(z))^{1-\theta_h} dz + \int_s^1 (P_{h,\tau}(z))^{1-\theta_h} dz \right)^{\frac{1}{1-\theta_h}} \tag{58}$$

and

[35] See Bacchetta and van Wincoop (2003) for the validity of this observation, where it is mentioned that in the main OECD countries the exchange rate pass-through to consumer prices is close to zero while the median estimate of the exchange rate pass-through to import prices is about 50%. This observation illustrates once more that the familiar Purchasing Power Parity (PPP) hypothesis is not realistic at all since, if PPP would be valid, the exchange rate pass-through would be complete; otherwise (as e.g. in the above observed situation) it is incomplete.

$$P_{f,\tau} \equiv \left(\int_0^s (P_{f,\tau}(z))^{1-\theta_f} dz + \int_s^1 (e_\tau P_{f,\tau}(z))^{1-\theta_f} dz \right)^{\frac{1}{1-\theta_f}} \tag{59}$$

where e_τ is the nominal exchange rate measuring the home currency price for one unit of the foreign (world) currency. Similarly, the price index of home exports of (consumption) goods $C^*_{h,\tau}$ can be expressed from (50) and (58) as:

$$P^*_{h,\tau} \equiv \left(\int_0^s (P^*_{h,\tau}(z))^{1-\theta^*_h} dz + \int_s^1 (e_\tau^{-1} P^*_{h,\tau}(z))^{1-\theta^*_h} dz \right)^{\frac{1}{1-\theta^*_h}}. \tag{60}$$

Final goods producers z are assumed to behave competitively, hire labor $N_{h,\tau}(z)$ (at fixed capacity $\overline{K}_{h,\tau}$) at the current nominal wage rate $W_{h,\tau}$, use intermediate goods $I_{f,\tau}(z)$ (which is an index of differentiated intermediate (imported) goods used by the final goods producer z), and maximize an expected discounted stream of profits each period. Considering a two-country world, the problem for the local (consumer) currency pricing firms (indexed by $z = 0, ..., s$) can be summarized as:

$$\max \quad E_t \sum_{\tau=t}^{\infty} \rho_\tau \pi_{h,\tau}(z)$$

with net profits for these local consumer currency pricing firms:

$$\begin{aligned} \pi_{h,\tau}(z) \quad \equiv \quad & P_{h,\tau}(z)Y_{h,\tau}(z) + e_\tau P^*_{h,\tau}(z)Y^*_{h,\tau}(z) - W_{h,\tau}N_{h,\tau} - \varphi_1(I_{f,\tau}(z)) + \\ & -\varphi_2(I^*_{f,\tau}(z)) - \varphi_3(\overline{K}_{h,\tau}) \end{aligned} \tag{61}$$

subject to an appropriate production technology. In (61) ρ_τ is assumed to be the commonly used discount factor at period τ, $Y_{h,\tau}(z)$ and $Y^*_{h,\tau}(z)$ are the final goods consumed in the home and foreign country, respectively, produced by the domestic firm z at period τ, and $I_{f,\tau}(z)$ is the index of differentiated (intermediate) goods imported by final goods producer z; this bundle of imported intermediate goods can be represented, again according to a CES-aggregate, as:

$$I_{f,\tau}(z) \equiv \left(\int_0^1 \left(I^j_{f,\tau}(z) \right)^{\frac{\vartheta-1}{\vartheta}} dj \right)^{\frac{\vartheta}{\vartheta-1}} \tag{62}$$

where $I^j_{f,\tau}(z)$ denotes the quantity (index) of foreignly produced intermediate goods of type j that is used by the domestic final goods producer z at period τ. Analogously, $I^{*i}_{f,\tau}(z)$ is considered as the quantity of domestically produced intermediate products of type i that is used by the foreign final goods producer, so that:

$$I^*_{f,\tau}(z) \equiv \left(\int_0^1 \left(I^{*i}_{f,\tau}(z) \right)^{\frac{\vartheta^*-1}{\vartheta^*}} di \right)^{\frac{\vartheta^*}{\vartheta^*-1}}. \tag{63}$$

The problem for the producer currency pricing firms (indexed by $z = s, ..., 1$) is identical to (61), except that $P^*_{h,\tau}$ is in units of home currency and the nominal exchange rate disappears from the second term of the profit expression.

How can the above-mentioned 'appropriate production technology' and the corresponding market structure be determined? Let us start with the market structure the analysis of which follows close that of the open economy consumer problem treated in the first part of this appendix. Consider therefore that, also following the CES aggregate of consumption goods (49), the aggregation technology for producing final goods in the two-country economy can be represented as:

$$Y_\tau \equiv \left[(1-\alpha_y)^{\frac{1}{\eta_y}} Y_{h,\tau}^{\frac{\eta_y-1}{\eta_y}} + \alpha_y^{\frac{1}{\eta_y}} Y_{f,\tau}^{\frac{\eta_y-1}{\eta_y}} \right]^{\frac{\eta_y}{\eta_y-1}}, \tag{64}$$

with η_y the elasticity of substitution between domestic and foreign goods ($\eta_y > 0$) and α_y determining the steady-state share of imported goods in total final goods output Y_τ; moreover, $Y_{h,\tau}$ represents an aggregate of the domestic final goods sold in the (small) open economy and $Y_{f,\tau}$ is an aggregate of the imported foreign (final) goods which can be defined similar to (45) as, which are also equal to optimal allocation for final outputs between domestic and foreign final goods (indexes) (see (51) and (52)):

$$Y_{k,\tau} \equiv \left(\int_0^1 Y_{k,\tau}(z)^{\frac{\vartheta_k-1}{\vartheta_k}} dz \right)^{\frac{\vartheta_k}{\vartheta_k-1}} = (1-\alpha_y) \left(\frac{P_\tau}{P_{h,\tau}} \right)^{-\eta_y} Y_\tau \quad (\text{for } k = h),$$
$$= \alpha_y \left(\frac{P_\tau}{P_{f,\tau}} \right)^{-\eta_y} Y_\tau \quad (\text{for } k = f)$$

with the elasticities of substitution between the differentiated final output goods given by $\vartheta_k > 1$ $(k = h, f)$.

Taking now the aggregate domestic final goods price, $P_{h,\tau}$, as given, we observe that from the definitions (54) for the aggregate price index and (58) and (59) for the price aggregation functions the following set of demand functions for the domestic final goods z is valid from the above definitions of aggregate outputs by substituting θ_k by ϑ_k $(k = h, f)$:

$$Y_{h,\tau}(z) = \left(\frac{P_{h,\tau}(z)}{P_{h,\tau}} \right)^{-\vartheta_h} Y_{h,\tau}, \tag{65}$$

and also the following demand functions for the foreign final goods:

$$Y_{f,\tau}(z) = \left(\frac{P_{f,\tau}(z)}{P_{f,\tau}} \right)^{-\vartheta_f} Y_{f,\tau} \quad \text{for } z = 0, ..., s \tag{66}$$

$$Y_{f,\tau}(z) = \left(\frac{e_\tau P_{f,\tau}(z)}{P_{f,\tau}} \right)^{-\vartheta_f} Y_{f,\tau} \quad \text{for } z = s, ..., 1. \tag{67}$$

Analogous conditions apply to the foreign country.

Regarding to an appropriate production technology we observe from the profit expression in (61) that the appropriate final output for domestic firm z is $Y_{h,\tau}(z) + Y^*_{h,\tau}(z)$,[36] where use has been made of the basic DSGE model property that output supply is assumed to be equal to output demand. Hence, the demand for the home-produced final good z is the sum of the demand by domestic consumers and the demand by the competitive export sector, which bundles the differentiated domestic final goods into a homogenous export (index of) good(s) or in a two-country setting from (57) and (50):

$$Y_{h,\tau}(z) + Y^*_{h,\tau}(z) = C_{h,\tau}(z) + C^*_{h,\tau}(z) = \left(\frac{P_{h,\tau}(z)}{P_{h,\tau}} \right)^{-\theta_h} \left(C_{h,\tau} + C^*_{h,\tau} \right) \tag{68}$$

where $C^*_{h,\tau}$ is the quantity of the (index of) good(s) that is consumed in the foreign country during period τ, but which originates from the domestic country; as noticed before, this quantity is equal to the final goods exports of the domestic country (which can be written as $X_{h,\tau}$). Since each final goods firm z in the home country is assumed to utilize a continuum of intermediate goods indexed by j, where j is distributed over the unit interval $(0, 1)$, we assume that each domestic final goods firm z transforms the (homogenous) labor and the imported intermediate goods bundle into (an) output goods according to a Leontief-technology:

$$Y_{h,\tau}(z) + Y^*_{h,\tau}(z) \equiv \min \left(\frac{\mu_{h,\tau} N_{h,\tau}(z)}{(1 - \alpha_{h,y})}, \frac{I_{f,\tau}(z)}{\alpha_{h,y}} \right) \tag{69}$$

where $\mu_{h,\tau}$ is an aggregate productivity shock common to all domestic final goods production firms (but which might originate from abroad) and $\alpha_{h,y}$ is the fixed proportion of output used by the intermediate (import) goods in the home country.

The solution of problem (61) with (69) as appropriate production technology leads to the efficient domestic final output relation:[37]

$$Y_{h,\tau}(z) + Y^*_{h,\tau}(z) = \frac{\mu_{h,\tau} N_{h,\tau}(z)}{(1 - \alpha_{h,y})} = \frac{I_{f,\tau}(z)}{\alpha_{h,y}}. \tag{70}$$

[36] Notice, however, that if the firm z does not only produce final goods, but also intermediary goods, the appropriate output to be considered for a production technology is $Y_{h,\tau}(z) + Y^*_{h,\tau}(z) + I^*_{f,\tau}(z)$ instead of $Y_{h,\tau}(z) + Y^*_{h,\tau}(z)$.

[37] Note that since perfect competition is assumed to exist on the final goods market, expected discounted profit minimization is equivalent to expected discounted cost minimization, so that (70) is also a cost minimizing output.

The production process of the (foreign) intermediate goods firms can be described by a situation where each intermediate good j is produced by a firm j using the following constant-returns-to-scale Cobb-Douglas technology:

$$Y_{f,\tau}(j) + Y^*_{f,\tau}(j) \equiv \mu_{f,\tau} \left(N_{f,\tau}(j)\right)^{\alpha_f} \left(\widetilde{K}_{f,\tau}(j)\right)^{(1-\alpha_f)} - \Phi \tag{71}$$

where $\mu_{f,\tau}$ is the productivity shock that hits all the intermediate goods firms in the foreign country at period τ, $N_{f,\tau}(j)$ is the labor input used by the foreign intermediate goods firm j during that period and which can be interpreted as an index of different types of labor used by that firm,[38] $\widetilde{K}_{f,\tau}(j)$ is the effective utilization of the capital stock by firm j at period τ and Φ is a real fixed cost (due to imperfect competition through sticky nominal prices in the intermediate goods market). Discounted profit maximization of the (foreign) intermediate goods firms with respect to the factor inputs implies an optimal trade-off between capital and labor inputs that depend on the relative cost of each:

$$\frac{W_{f,\tau} N_{f,\tau}(j)}{r_{f,\tau} \widetilde{K}_{f,\tau}(j)} = \frac{\alpha_f}{(1-\alpha_f)} \tag{72}$$

so that the capital-labor ratio of the (foreign) intermediate goods firms is identical across all intermediate goods producers and is, hence, equal to the aggregate capital-labor ratio.

The labor used by each firm in any country is assumed to be a CES-aggregate of individual household labor:[39]

$$N_{k,\tau}(z) \equiv \left(\int_0^1 \left(N^i_{k,\tau}(z)\right)^{\frac{\vartheta_k - 1}{\vartheta_k}} di \right)^{\frac{\vartheta_k}{\vartheta_k - 1}} \qquad \text{for } k = h, f \tag{73}$$

where $N^i_{k,\tau}(z)$ is the number of household i's working hours in firm z at period τ and the elasticity of labor demand ϑ_k is assumed to be larger than unity as before. The cost-minimizing quantity $N^i_{k,\tau}(z)$ satisfies then for $k = h, f$, taking account of (65) and (66):

$$N^i_{k,\tau}(z) = \left(\frac{W^i_{k,\tau}}{W_{k,\tau}} \right)^{-\vartheta_k} N_{k,\tau}(z) \tag{74}$$

with aggregate domestic labor, taking account of the cost-minimizing Leontief production technology for the final goods producers involved in (70):

$$N_{h,\tau} \equiv \int_0^1 N_{h,\tau}(z) dz = \int_0^1 \frac{\left(Y_{h,\tau}(z) + Y^*_{h,\tau}(z)\right)(1-\alpha_{h,y})}{\mu_{h,\tau}} dz \tag{75}$$

[38] This labor input will be defined in (73).

[39] Notice that the elasticity of labor demand is assumed to be the same across workers, but may vary over time; henceforth, it will be denoted as ϑ_τ.

Hence, by substituting the aggregating equation (68) into equation (75) and manipulating we obtain:

$$Y_{h,\tau} + Y^*_{h,\tau} = \frac{\mu_{h,\tau} N_{h,\tau}}{(1-\alpha_{h,y})\, V_{h,\tau}} \equiv C_{h,\tau} + C^*_{h,\tau} \tag{76}$$

where $V_{h,\tau} \equiv \int_0^1 \left(\frac{P_{h,\tau}(z)}{P_{h,\tau}}\right)^{-\theta_h} dz$ is a measure of relative price dispersion in the domestically produced goods sector, which will always be greater than or equal to one and will rise with the variance of domestic prices.[40]

Aggregating (68) over all domestic final goods producers and using equations (51) and (76), we obtain an expression for the aggregate final domestic output demand $\overline{Y}_{h,\tau}$, taking (76) into account:

$$\begin{aligned}
\overline{Y}_{h,\tau} &\equiv Y_{h,\tau} + Y^*_{h,\tau} = \int_0^1 \left(\frac{P_{h,\tau}(z)}{P_{h,\tau}}\right)^{-\theta_h} \left[(1-\alpha_c)\left(\frac{P_{h,\tau}}{P_\tau}\right)^{-\eta_c} C_\tau + X_{h,\tau}\right] dz \\
&= V_{h,\tau}\left[(1-\alpha_c)\left(\frac{P_{h,\tau}}{P_\tau}\right)^{-\eta_c} C_\tau + X_{h,\tau}\right], \qquad (77)
\end{aligned}$$

which can be referred to as the overall domestic goods market equilibrium equation.

Choosing labor services to minimize costs conditional on output yields for the marginal cost of domestic firm z:

$$MC_{h,\tau}(z) = \frac{(W_{h,\tau}/P_\tau)}{\mu_{h,\tau} f'(f^{-1}(Y_{h,\tau}/\mu_{h,\tau}))} \tag{78}$$

where f is the production function expression in labor input (the productivity shock $\mu_{h,\tau}$ is assumed to be exogenous) , f' is its derivative with respect to this labor and $f^{-1}(.)$ its inverse function. Hence, following the ideas proposed by Galí and Gertler (1999), Galí *et al.* (2001), Jondeau and Le Bihan (2001), Leith and Malley (2002), and Sbordone (2002)[41] the real marginal cost for the domestic final goods firms can be derived from substitution of (70) in (78):

$$\begin{aligned}
MC_{h,\tau}(z) &= \frac{W_{h,\tau}}{P_\tau}\frac{\partial N_{h,\tau}(z)}{\partial\left(Y_{h,\tau}(z) + Y^*_{h,\tau}(z)\right)} + \frac{P_{f,\tau}(z)}{P_\tau}\frac{\partial I_{f,\tau}(z)}{\partial\left(Y_{h,\tau}(z) + Y^*_{h,\tau}(z)\right)} = \\
&= (1-\alpha_{h,y})\frac{W_{h,\tau}}{\mu_{h,\tau} P_\tau} + \alpha_{h,y}\frac{P_{f,\tau}(z)}{P_\tau} \qquad (79)
\end{aligned}$$

[40] One is the steady-state value of $V_{h,\tau}$ when all prices of the differentiated goods are assumed to be equal.

[41] These authors show that it is only in the absence of labor market frictions that the output gap $\widehat{y}_\tau$ is proportional to marginal costs' deviations and that the output gap may be replaced by a measure of demeaned marginal costs.

which is, according to the assumed constant-returns-to-scale (Leontief) technology and the aggregate nature of shocks, the same across all final goods firms in the home country. Similarly, the real marginal cost for the (foreign) intermediate goods firms can be derived from substitution of (71) in (78):

$$MC_{f,\tau}(z) = \frac{(W_{f,\tau}/P_\tau)^{\alpha_f} (r_{f,\tau}/P_\tau)^{(1-\alpha_f)} (1-\alpha_f)^{-(1-\alpha_f)} (\alpha_f)^{-\alpha_f}}{\mu_{f,\tau}} \; , \qquad (80)$$

so that the (real) marginal cost is found to be independent again of the (foreign) intermediate goods produced.

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