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Contents

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Abstract

Recent research on the new Phillips curve (NPC) (e.g., Galí, Gertler, and López-Salido 2001a) gives marginal cost an important role in capturing pressures on inflation. In this paper we assess the case for using alternative measures of marginal cost to improve the empirical fit of the NPC. Following Sbordone (2000), we derive the aggregation factors when firms use Cobb-Douglas with overhead labour and constant elasticity of substitution (CES) technologies. We estimate the NPC for Canada, the United States, and the euro area. Our structural results indicate that: (i) ignoring aggregation factors gives implausibly large estimates of the duration of price stickiness—in this respect, the aggregation factors improve the fit of the NPC substantially; (ii) the marginal cost measures based on CES technology improve the fit of the NPC relative to the Cobb-Douglas technology, particularly for Canada and the euro area; (iii) for Canada, the backward-looking component of inflation is quite strong relative to the United States and the euro area; and (iv) the incorporation of open-economy considerations for Canada does not yield better estimates of the NPC.

JEL classification: E31
Bank classification: Economic models; Inflation and prices

Résumé

Dans les travaux consacrés récemment à la « nouvelle courbe de Phillips » (par exemple ceux de Galí, Gertler et López-Salido, 2001a), le coût marginal se voit attribuer un rôle important dans la mesure des pressions s'exerçant sur l'inflation. Édith Gagnon et Hashmat Khan tentent de déterminer si l'emploi de différentes mesures du coût marginal peut améliorer l'adéquation statistique de la nouvelle courbe de Phillips aux faits observés. En s'inspirant des recherches de Sbordone (2000), ils établissent les facteurs d'agrégation applicables selon que les entreprises utilisent une fonction de production à élasticité constante de substitution (CES) ou une fonction Cobb-Douglas dans laquelle une certaine quantité de main-d'œuvre est affectée à des activités non directement liées à la production. Les auteurs estiment la nouvelle courbe de Phillips pour le Canada, les États-Unis et la zone euro. Voici les résultats qu'ils obtiennent à partir de la forme structurelle du modèle : i) si l'on ne fait appel à aucun facteur d'agrégation, la fréquence à laquelle les prix sont modifiés est très faible d'après les estimations et peu plausible — le recours à un facteur d'agrégation permet d'améliorer sensiblement l'adéquation de la nouvelle courbe de Phillips sur ce plan; ii) celle-ci rend également mieux compte de la réalité si la mesure du coût marginal est fondée sur une fonction de production CES plutôt que Cobb-Douglas, en particulier dans le cas du Canada et de la zone euro; iii) le poids accordé à la composante rétrospective de l'inflation est plus élevé dans le cas du Canada; iv) l'adoption d'un cadre d'économie ouverte n'aboutit pas à de meilleures estimations de la nouvelle courbe de Phillips dans le cas du Canada.

Classification JEL : E31
Classification de la Banque : Modèles économiques; Inflation et prix

1. Introduction

Understanding the short-run dynamics of inflation is important for monetary policy decisions. The recent generation of optimizing models with nominal rigidities has provided a framework in which to think about the determinants of inflation, and to address issues concerning the conduct and optimality of monetary policy.[1] Within this framework, the process of inflation is described by the so-called "new Phillips curve" (NPC). The main advantage of the NPC over the traditional Phillips curve is that the former has a theoretical foundation and, therefore, a clear structural interpretation, whereas the latter is a reduced-form relationship. This aspect of the NPC is potentially useful for interpreting the dynamics of inflation in the presence of structural changes. From a policy perspective, it is therefore useful to investigate how well the NPC fits the data.

According to the NPC, current inflation is determined by the expectation of future inflation and the current output gap. This formulation, however, has met with many empirical difficulties.[2] Specifically, the estimated coefficient on the output gap has a negative sign, unlike what the model predicts.[3] The recent work of Galí and Gertler (1999) (hereafter GG), Sbordone (2000), and Galí, Gertler, and López-Salido (2001a) (hereafter GGL) has argued that inflation dynamics can be better explained by a marginal cost-based, rather than output gap-based, NPC. GG and GGL provide supporting evidence for the United States and the euro area.[4] These authors also modify the basic form of the NPC by allowing rule-of-thumb behaviour in price-setting on the part of some firms in the economy. This "hybrid" formulation is able to account for the observed persistence in inflation.

[1] Some prominent examples are Yun (1996), Woodford (1996, 1999a, 1999b), Rotemberg and Woodford (1997), McCallum and Nelson (1999). Goodfriend and King (1997, 2001), Galí (2000), and King (2001) provide excellent discussions of this framework.

[2] See, for example, Fuhrer and Moore (1995), Fuhrer (1997), Roberts (1997), and, more recently, Mankiw (2000).

[3] The output gap-based NPC predicts that inflation leads the output gap, and that past inflation does not matter for the determination of current inflation. In the U.S. data, however, the output gap seems to lead inflation.

[4] The empirical implementation of the marginal cost-based NPC has the advantage that it is not subject to any measurement problems associated with a "detrended" measure of the output gap. Further, the proportionality of the marginal cost and the output gap, which arises under the assumption of frictionless labour markets, is not required to hold in the estimation.

Their estimates of the hybrid NPC indicate the presence of a small but significant departure from the fully rational forward-looking model.

The emphasis on marginal cost is natural, given that the pricing decisions of firms are based on this variable. The pricing decisions of firms, in turn, feed into the aggregate inflation rate. The empirical implementation of the marginal cost-based NPC raises two issues. First, the NPC is derived from a model in which firms face constraints on price adjustments. This set-up implies that relative prices, and hence output levels, differ across firms. Therefore, firm-level marginal costs (which are unobservable) may not necessarily be the same as the average aggregate measure of marginal cost (which is observable and approximated by the labour income share). Sbordone (2000) derives an aggregation factor under the assumptions of Cobb-Douglas (CD) technology and the Calvo (1983) formulation of price stickiness. Similarly, a consideration of alternative technologies requires specific aggregation factors. Second, the average aggregate marginal cost is generally approximated by the labour income share. This approximation requires that firms produce using a CD technology.[5] But if this is not the case, as in when firms use overhead labour, non-CD technology, or face labour-adjustment costs, the labour income share has to be augmented to better represent marginal cost (see Rotemberg and Woodford 1999). Wolman (1999) hypothesizes that a consideration of these alternative measures of marginal cost could improve the empirical fit of the NPC.

In this paper, we derive aggregation factors for CD with overhead labour (CDOL), constant elasticity of substitution (CES), and CES with overhead labour (CESOL). We then assess the case for using alternative marginal cost measures to improve the fit of the NPC. To begin, we undertake reduced-form analysis of inflation for Canada. Then we conduct a structural analysis of inflation

[5] With labour as the variable input. Nominal wages are assumed to be flexible and allocative. However, Erceg, Henderson, and Levin (2000) demonstrate the importance of nominal wage rigidity in optimal monetary policy analysis.

for Canada and extend the work of GGL for the United States and the euro area. Our paper is closely related to work by Galí and López-Salido (2000), who consider alternative marginal cost measures to understand inflation dynamics in Spain.[6] They, however, assume that the aggregation factor under the CD technology applies to other measures of marginal cost. We find that the role of technology-specific aggregation factors is quantitatively important.

The reduced-form estimates indicate two things. First, the criticisms of the output gap-based NPC in the literature apply to a lesser degree for Canada. In contrast to the United States and the euro area, the sign of the estimated coefficient of the output gap for Canada is positive. Hence, its economic significance is consistent with the theory. Second, for the hybrid output gap-based NPC specification, the coefficient on the ouput gap is statistically insignificant for all countries.[7]

The structural estimates of the marginal cost-based NPC provide four main conclusions. First, in the empirical implementation of the NPC, ignoring the aggregation factors implied by the model gives implausibly large estimates of the duration of price stickiness. With the aggregation factors, the estimated duration of price stickiness is substantially smaller and more plausible. Hence, the fit of the NPC with the data is better. Second, the marginal cost measures based on CES and CESOL give better estimates of the NPC relative to the CD-based measure. Third, the backward-looking component in inflation is the largest for Canada relative to the United States and the euro area. Fourth, the incorporation of open-economy considerations for Canada does not improve the fit of the NPC relative to the closed-economy case.

The rest of this paper is organized as follows. In section 2 we describe the theory behind the NPC and derive the aggregation factors. In section 3 we describe the data and the estimation methodology, and present the results. Section 4 concludes.

[6]Other recent studies that examine the role of labour income share in the context of the NPC are Amato and Gerlach (2000) and Batini, Jackson, and Nickell (2000).

[7]For convenience, we refer to the euro area as a country.

2. Theory

Consider a monopolistically competitive market structure with a continuum of firms distributed uniformly on a unit interval.[8] Each firm, indexed by $z \in [0,1]$, produces a differentiated good, $Y_t(z)$. A typical firm, z, faces a downward-sloping demand curve, $Y_t(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\epsilon} Y_t$, for its product. The nominal price charged by the firm per unit of output is $P_t(z)$. The aggregate price, P_t, and output, Y_t, are represented as $P_t = [\int_0^1 P_t(z)^{1-\epsilon} dz]^{\frac{1}{1-\epsilon}}$ and $Y_t = [\int_0^1 Y_t(z)^{\frac{\epsilon-1}{\epsilon}} dz]^{\frac{\epsilon}{\epsilon-1}}$, respectively. The parameter, ϵ, is the constant price elasticity of demand facing a firm, as well as the Dixit-Stiglitz elasticity of substitution between the differentiated goods. Each firm faces a constraint on the frequency of price adjustment that it can undertake in response to shocks. This constraint reflects sticky prices and staggered pricing decisions across firms. A tractable way to capture these aspects is described by Calvo (1983).[9] Under the Calvo set-up, each firm faces a constant probability, $1-\theta$, of adjusting its price in any given period, independent of the history of previous price adjustments. The expected duration for which a firm's price can remain unchanged is then $\frac{1}{1-\theta}$.

Each firm operates with a CD technology, $Y_t(z) = K_t(z)^\alpha (A_t N_t(z))^{1-\alpha}, \alpha \in [0,1]$, where $K_t(z)$ and $A_t N_t(z)$ represent a firm's capital and effective-labour requirements to produce its output. A_t represents a common labour-augmenting technology shock. By minimizing the cost of producing a given level of output, a firm determines its real marginal cost, $MC_t(z)$, of producing an additional unit of output.

At time t, a fraction, $1-\theta$, of firms are able to reset their price. The profit-maximization problem for every price-adjusting firm is identical. Therefore, each firm chooses the same optimal price, P_t^*, by maximizing the expected discounted profits given the technology and demand conditions, and

[8] The discussion of the theoretical model follows Yun (1996), Rotemberg and Woodford (1997), and Goodfriend and King (1997).

[9] An alternative is to follow Rotemberg (1982) and assume quadratic cost of price adjustment.

the possibility of price stickiness in future periods. Formally,

$$\max_{P_t(z)} \sum_{j=0}^{\infty} \theta^j E_t \left[R_{t,t+j} \left(\frac{P_t(z)}{P_{t+j}} - MC_{t,t+j}(z) \right) Y_{t,t+j}(z) \right], \tag{2.1}$$

where $Y_{t,t+j}(z)$ represents the demand facing the firm at time $t+j$ whose price is set at time t. Similarly, $MC_{t,t+j}(z)$ represents the real marginal cost of producing a unit of output at time $t+j$ when the price of the product is set at time t. $R_{t,t+j}$ is the stochastic discount factor that defines the present value at t of real income at time $t+j$. Defining the relative price, $X_t \equiv \frac{P_t^*}{P_t}$, the log-linear approximation (around a zero-inflation, flexible-price equilibrium) of a firm's optimal pricing rule is[10]:

$$\hat{x}_t = (1-\theta\beta) \sum_{j=0}^{\infty} (\theta\beta)^j E_t \left[\hat{mc}_{t,t+j}(z) + \sum_{k=1}^{j} \pi_{t+k} \right]. \tag{2.2}$$

That is, the optimal price depends on the current and future realizations of the real marginal cost. β is the subjective discount factor. $\hat{mc}_{t,t+j}(z)$ is the deviation of the real marginal cost from its steady-state level, μ^{-1}, where μ is the desired markup under flexible prices. The aggregate price level evolves according to $P_t = \left[(1-\theta)(P_t^*)^{1-\epsilon} + \theta P_{t-1}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$ and its log-linear approximation is

$$\pi_t = \frac{1-\theta}{\theta} \hat{x}_t, \tag{2.3}$$

where π_t is the inflation rate.

The firm-level marginal cost terms in (2.2) are unobservable. On the other hand, the average aggregate marginal cost measure (represented by the real unit labour cost, or the labour income share) is observable. For the empirical implementation, it is necessary to specify the NPC in terms of this observable marginal cost measure. To accomplish this, Sbordone (2000) assumes that differences in relative prices do not influence the capital stock levels across firms. Then the

[10] Appendix A presents all the derivations. Notation: "$\hat{z}_t$" denotes the log deviation of a variable Z_t from its flexible-price equilibrium (steady-state) value.

relationship between the unobservable firm-level marginal cost and the average aggregate marginal cost is

$$\hat{mc}_{t,t+j}(z) = \hat{mc}^{avg}_{t+j} - h\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right), \tag{2.4}$$

and

$$h \equiv \frac{\epsilon\alpha}{1-\alpha}. \tag{2.5}$$

The term h is the "aggregation factor" corresponding to the CD technology with decreasing returns to labour (or upward-sloping marginal cost schedules). The interpretation of (2.4) is as follows: the term $(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k})$ represents the relative price in period $t+j$ of the firm that chooses the price, P_t^*, in period t. The higher the relative price of a firm (i.e., $\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k} > 0$), the lower the demand for its product, the lower its sales, and the smaller the firm's marginal cost relative to the average.

We get the NPC by substituting (2.4) in (2.2) and using (2.3):

$$\pi_t = \beta E_t\pi_{t+1} + \lambda\left(\frac{1}{1+h}\right)\hat{mc}^{avg}_t; \quad \lambda \equiv \frac{(1-\theta)(1-\theta\beta)}{\theta}, \tag{2.6}$$

where the average aggregate marginal cost, $\hat{mc}^{avg}_t$, is approximated by $\hat{s}_t$. The latter term is the log deviation of the labour income share (S_t) from its steady-state, s, where $s = \ln S$ and $S = \frac{\sum_t^T S_t}{T}$ (the sample mean). Note that the slope of the NPC is influenced by the frequency of price adjustment, θ, the discount factor, β, and the aggregation factor, h.

2.1. Alternative measures of marginal cost and aggregation factors

In addition to the standard CD technology, we consider CDOL, CES, and CESOL technologies. Two issues arise. First, to obtain the appropriate average aggregate marginal cost, we augment the labour income share following Rotemberg and Woodford (1999). Second, we derive the aggregation factors for these technologies using the same assumptions as Sbordone (2000).[11]

2.1.1 CDOL

Consider a CD technology with overhead labour:

$$Y_t(z) = K_t(z)^{\alpha}(A_t(N_t(z) - \overline{N}))^{1-\alpha}, \quad 0 < \alpha < 1, \quad \overline{N} > 0. \tag{2.7}$$

The term $\overline{N}$ indicates the presence of overhead labour; that is, the labour that must be hired by the firm independent of the quantity of output that it produces.[12] The relationship between the firm-level marginal cost and the average aggregate marginal cost (corresponding to (2.4), and with similar interpretation) in this case is

$$\hat{mc}_{t,t+j}(z) = \underbrace{\hat{s}_{t+j} - b\hat{n}_{t+j}}_{\hat{mc}^{avg}_{t+j}} - h\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right); \quad b = \frac{-\overline{N}/N}{1 - \overline{N}/N}. \tag{2.8}$$

The term $\hat{s}_t - b\hat{n}_t$ represents the average aggregate marginal cost measure at time t. The aggregation factor under this technology is

$$h^{cdol} \equiv \frac{\epsilon\alpha}{1-\alpha}, \tag{2.9}$$

which is the same as for the CD case in Sbordone (2000).

2.1.2 CES

Consider the following CES technology:

$$Y_t(z) = \left[K_t^{\frac{\sigma-1}{\sigma}}(z) + (A_t N_t(z))^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \quad \sigma \neq 1. \tag{2.10}$$

The relationship corresponding to (2.4) in this case is

[11] See Appendix A for details.

[12] Overhead labour is assumed to be acyclical.

$$\hat{mc}_{t+j}(z) = \underbrace{\hat{s}_{t+j} - a\hat{y}_{t+j}}_{\hat{mc}^{avg}_{t+j}} - h(\hat{x}_t - \sum_{k=1}^{j} \pi_{t+k}), \quad a \equiv (1-\sigma^{-1})(\mu^{-1}S^{-1} - 1). \tag{2.11}$$

The term $\hat{s}_t - a\hat{y}_t$ represents the average aggregate marginal cost measure at time t. The aggregation factor under the CES technology is

$$h^{ces} = \epsilon \left(\frac{1-\mu S}{\sigma \mu S} \right). \tag{2.12}$$

2.1.3 CESOL

Consider the following CESOL technology:

$$Y_t(z) = F(K_t(z), A_t(N_t(z) - \overline{N})) = \left[K_t^{\frac{\sigma-1}{\sigma}}(z) + (A_t(N_t(z) - \overline{N}))^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad \sigma \neq 1. \tag{2.13}$$

The relationship corresponding to (2.4) in this case is

$$\hat{mc}_{t+j}(z) = \underbrace{\hat{s}_{t+j} - a^{cesol}\hat{y}_{t+j} - b\hat{n}_{t+j}}_{\hat{mc}^{avg}_{t+j}} - h(\hat{x}_t - \sum_{k=1}^{j} \pi_{t+k}), \tag{2.14}$$

where $\hat{s}_t - a^{cesol}\hat{y}_t - b\hat{n}_t$ is the average aggregate marginal cost measure at time t and $a^{cesol} = (1 - \sigma^{-1}(\mu^{-1}S^{-1}\frac{N}{N-\overline{N}} - 1))$. The aggregation factor under the CESOL technology is

$$h^{cesol} = \epsilon \left[\frac{1}{\mu S} - 1 - \left(\frac{\sigma - 1}{\sigma} \right) \left(\frac{\frac{N}{N-\overline{N}} - \mu S}{\mu S} + \frac{\frac{\overline{N}}{N-\overline{N}}}{\mu S} \right) \right]. \tag{2.15}$$

Note that when $\overline{N} = 0$, $h^{cesol} = h^{ces}$.

2.2 Hybrid NPC

The persistence of inflation in the data (for the United States, Canada, and the euro area) is challenging for the sticky-price model described in section 2.1. The model does not have any structural persistence in inflation, as is evident from (2.6). One direction to explore is whether the model in section 2.1 is in fact consistent with the reduced-form inflation persistence.[13] Alternatively, the model in section 2.1 could be modified to incorporate structural persistence in inflation. For instance, GG and GGL present a *hybrid* model, in which a fraction, ω, of the firms that are able to set their price in a given period choose a rule-of-thumb pricing rule.[14] This modification introduces a backward-looking component of inflation into an otherwise completely forward-looking NPC. The hybrid NPC specification thus obtained is

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \tilde{\lambda}(\frac{1}{1+h})\hat{mc}_t^{avg}, \tag{2.16}$$

where

$$\tilde{\lambda} \equiv (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1}; \quad \gamma_b \equiv \omega\phi^{-1}; \quad \gamma_f \equiv \beta\theta\phi^{-1},$$

and $\phi \equiv \theta + \omega[1-\theta(1-\beta)]$. Note that when $\omega = 0$, the hybrid NPC is the same as the forward-looking NPC in (2.6). We estimate (2.16) along with the forward-looking specification (2.6).

3. Data, Estimation, and Results

3.1 Data

We use quarterly data with the sample periods 1970Q1 to 2000Q4 for Canada, 1970Q1 to 2001Q1 for the United States, and 1970Q1 to 1998Q4 for the euro area.[15] Figure 1 plots the annualized inflation rate (quarterly change in the total GDP deflator) and the output gap (quadratic detrended) for Canada, the United States, and the euro area.

[13] See Goodfriend and King (2001) for a detailed discussion of this point.
[14] An early attempt along this line is presented in Fuhrer and Moore (1995).
[15] See Appendix B for a complete description of variables and data sources.

3.2 GMM estimation

We estimate the parameters of the NPC by the generalized method of moments (GMM) (Hansen 1982). Following GGL, the instrument set consists of lagged variables for inflation, output gap, marginal cost, and wage inflation. The standard errors of the estimated parameters are modified using the Newey-West correction. We test the model's overidentifying restrictions based on the J-statistic. The model restrictions imply that not all parameters can be estimated. We therefore calibrate a subset of parameters to get a value for the aggregation factor. These parameters are $\{\mu, S, \sigma\}$. Given the steady-state value of the desired markup, μ, and the sample mean of the labour income share, S, we can calibrate α as[16]

$$\alpha = 1 - \mu S. \tag{3.1}$$

Also, given a value for μ, the demand structure of the model allows the elasticity parameter to be calibrated as $\epsilon = \frac{\mu}{\mu-1}$. We use $\mu = 1.1$ from Basu and Fernald (1997). For Canada, S is the sample mean of the labour income share and it equals 0.56; for the United States and the euro area we follow GGL and use the values $S = 0.66$ and $S = 0.75$, respectively. The CES and the overhead labour cases require the additional parameters σ and b, respectively. Following Rotemberg and Woodford (1999), we calibrate[17]

$$b = \frac{-(\mu - 1)}{\mu S - (\mu - 1)}, \tag{3.2}$$

and $\sigma = \frac{1}{2}$. We assume that the parameters $\{\mu, \sigma\}$ are the same across countries. Table 1 summarizes the parameter values and the corresponding values of the aggregation factors.

[16] In the steady-state, $MC^{avg} = \mu^{-1}$. The marginal cost measure under the CD technology is $MC^{avg} = \frac{WN}{(1-\alpha)PY} \equiv \frac{S}{1-\alpha}$.

[17] As Rotemberg and Woodford (1999) show, instead of calibrating $\frac{\overline{N}}{N}$ to get a value of b, we can calibrate the returns to scale (ratio of average cost to marginal cost) and make long-run profits zero because of the exit and entry of firms. The latter assumption implies that the returns to scale are identical to the markup.

3.3 Reduced-form output gap-based NPC

3.3.1 The sign of the estimated coefficient on the output gap

We first estimate a reduced-form output gap-based NPC for Canada, to document whether the criticisms of this formulation apply to the Canadian data. From (2.6) and (2.16) (replacing the marginal cost term with the output gap), the orthogonality conditions for the output gap-based NPC are

$$E_t[(\pi_t - \beta\pi_{t+1} - \kappa\hat{y}_t)\mathbf{z}_t] = 0; \qquad \kappa = \kappa^*\lambda, \tag{3.3}$$

and

$$E_t[(\pi_t - \gamma_f\pi_{t+1} - \gamma_b\pi_{t-1} - \kappa\hat{y}_t)\mathbf{z}_t] = 0, \tag{3.4}$$

for the forward-looking and hybrid NPCs, respectively. Assuming a proportionality between marginal cost and the output gap, $\hat{mc}_t = \kappa^*\hat{y}_t$, the coefficient on the output gap is κ. The set of instruments $\mathbf{z_t}$, consists of four lags ($t-1$ to $t-4$) of inflation, output gap, marginal cost, and wage inflation, as in GGL.

Table 2 presents the results for the output gap-based NPC.[18] Note that the estimated coefficient, κ, for the United States has the wrong sign ($\kappa = -0.011$), and is statistically significant at the 1 per cent level. For the euro area, the estimated coefficient has a negative sign, as well (although it is not statistically significant). A similar finding in Sbordone (2000), GG, and GGL has motivated the structural analyis of inflation based on marginal cost. For Canada, however, the estimate of κ has a positive sign, which is consistent with the theory (although it is not statistically significant). This suggests that the criticisms of the output gap-based NPC apply to a lesser degree for Canada.

For the hybrid output gap-based NPC, we find that both Canada and the euro area have a positive coefficient. The coefficients, however, are statistically insignificant for the three countries.[19]

[18] The results for HP-filter data are qualitatively similar.

[19] The statistical insignificance is potentially related to the quarterly frequency of the data (see, for example, Roberts 1997).

The weight on the backward-looking component of inflation is statistically significant at the 1 per cent level.[20]

3.4 Structural estimation results

We now estimate the structural specifications to obtain the estimates of the key parameters (β, θ, ω) of the model. From (2.6) and (2.16), the orthogonality conditions are

$$E_t[(\pi_t - \beta\pi_{t+1} - \theta^{-1}(1-\theta)(1-\theta\beta)(\frac{1}{1+h})\hat{mc}^{avg})\mathbf{z}_t] = 0, \tag{3.5}$$

and

$$E_t[(\pi_t - \omega\phi^{-1}\pi_{t-1} - \beta\theta\phi^{-1}\pi_{t+1} - \phi^{-1}(1-\theta)(1-\theta\beta)(\frac{1}{1+h})\hat{mc}^{avg})\mathbf{z}_t] = 0, \tag{3.6}$$

for the forward-looking and the hybrid NPC's, respectively, with $\phi \equiv \theta + \omega[1 - \theta(1-\beta)]$.

The instrument variables for the United States and the euro area are the same as above. For Canada, we use $t-2$ to $t-5$ lags of inflation, output gap, marginal cost, and wage inflation.[21]

3.4.1 Benchmark case: Cobb-Douglas technology based marginal cost measure

In this section, we consider a measure of marginal cost based on the assumption of CD with decreasing returns to labour technology (i.e., $\frac{1}{1+h^{cd}} < 1$). GGL use this measure to estimate the NPC for the United States and the euro area, and therefore it establishes a benchmark by which to compare the results for Canada. The results are reported in Tables 3a-c for Canada, the United States, and the euro area, respectively. The results for the United States and the euro area are similar to the one in GGL.[22] For Canada, the estimated coefficient, λ, is positive, as predicted

[20] The J-statistic does not reject the overidentifying restrictions. The reduced-form results for the marginal cost-based NPC are not reported here, owing to space limitations. The results are qualitatively similar to the structural estimates reported in section 3.4.

[21] The structural estimation for Canada encountered convergence problems when we used the $t-1$ set of instrument variables (or its subset). For each GMM estimation, we applied the F-test to the first-stage regressions, to check the potential weakness of the instruments, as Staiger and Stock (1997) recommend. These tests indicated that the instruments used in the estimation are relevant.

[22] We thank Mark Gertler and David López-Salido for sending us their programs to replicate the results of the CD case for the United States and the euro area that were reported in GGL.

by the theory. But it is not statistically significant. This finding suggests that, unlike the United States and the euro area, the forward-looking NPC for Canada has a relatively weak fit.

The hybrid NPC specification for Canada performs slightly better, as λ is statistically significant at the 10 per cent level. However, the estimated discount factor, β, is 0.85. This value is much lower than the calibrated value of 0.99 for quarterly data typically used in theoretical models. Furthermore, the degree of backward-looking behaviour is quite large. The estimate of ω, which represents the rule-of-thumb behaviour in the model, is almost 0.5. This estimated value implies that approximately 50 per cent of all the price-setters in a given quarter follow a backward-looking pricing strategy. The overall weight on the backward-looking component of inflation, γ_b, is almost as large as the weight on the forward-looking component, γ_f.

The estimated duration of price stickiness, D $(= \frac{1}{1-\theta})$, in Canada is similar to that in the United States for both the forward-looking (4.6 and 4.1 quarters, respectively) and the hybrid specification (2.6 and 3.6 quarters, respectively). For the euro area the corresponding estimates are relatively higher (6.1 and 6.0 quarters, respectively).

3.4.2 Alternative marginal cost measures and aggregation factors

In this section, we assess the case for using alternative measures of marginal cost to improve the fit of the NPC as conjectured by Wolman (1999). Initially, we abstract from the aggregation issue (i.e., we impose $\frac{1}{1+h} = 1$), to isolate the effect of alternative marginal cost measures alone. Figure 2 plots the four measures of marginal cost: CD, CDOL, CES, and CESOL (as log deviations from the steady state).

The results from the forward-looking specifications in Tables 3a-c indicate that the estimated duration of price stickiness is implausibly large.[23] For example, the estimates of D for Canada sug-

[23] The Ljung-Box test detected residual autocorrelation in the forward-looking case. The presence of residual autocorrelation also motivates the consideration of the hybrid NPC, as in GGL. Roberts (2001) examines this aspect

gest that, on average across the marginal cost measures, prices do not change for about 12 quarters. For the United States and the euro area, the corresponding estimates are around 10 quarters and 12 quarters, respectively. We find qualitatively similar results for the hybrid specification within each country. Even though the estimates of D in the hybrid specification are lower relative to the forward-looking specification for the three countries, they are still unrealistic. This finding resembles the results of Galí and López-Salido (2000) for Spain.

We now conduct the estimation with the aggregation factors implied by the model for the alternative technologies (i.e., $\frac{1}{1+h} < 1$). The main influence of the aggregation factors is on the estimated duration of price stickiness. We find that the average estimate of D for Canada and the United States is similar across the forward-looking and hybrid specifications. For the forward-looking case the average estimate is below 4 quarters, and for the hybrid it is below 3 quarters. The corresponding average estimates for the euro area are higher (approximately 5 quarters). This range of estimates of D, conditional upon the aggregation factors, is quite plausible, and hence suggests a better performance of the NPC.

We find that, for Canada and the euro area, marginal cost based on CES and CESOL improves the fit of the NPC along two dimensions: the statistical significance of λ, and the estimated value of D. The coefficient λ is statistically significant for both forward-looking and hybrid specifications for Canada. For these cases, the estimated D is smaller than the CD cases. Similarly, for the euro area, the estimated λ of the hybrid specification is statistically significant and the estimates of D are smaller than the CD cases. For the United States, even though λ remains statistically significant across all the measures of marginal cost, the CES cases give smaller estimates of D.

The results for the alternative measures indicate an improvement in the fit of the NPC relative to the benchmark case reported in section 3.4.1. We find that the CES cases yield relatively lower

of the NPC in greater detail.

estimates of D for the three countries. Furthermore, the backward-looking behaviour is consistently large for Canada relative to the United States and the euro area.

3.4.3 Sensitivity analysis

We examine the sensitivity of the estimated D to the steady-state value of the labour share and the markup under each measure of marginal cost. The estimated D under forward-looking and hybrid NPC specifications (with a 95 per cent confidence interval) is reported in Figures 3 to 8. In the first experiment, we hold the steady-state markup fixed ($\mu = 1.1$) and vary the mean of the labour income share in the range of $(S - 0.1, S + 0.1)$ to examine the sensitivity of D. In the second experiment, we fix the labour income share and vary the steady-state markup from 1.1 to 1.45. We find a positive dependence of the estimated D on the steady-state markup and the labour share under each marginal cost measure. Further, the estimated duration is more responsive to changes in the steady-state markup than to the steady-state labour income share. These results contrast with Galí and López-Salido's (2000) results for Spain. They find that the estimated duration is not sensitive to either changes in the steady-state markup or the steady-state labour income share.

3.4.4 An open-economy specification for Canada

As discussed in section 3.4.1, for Canada, the forward-looking specification of the NPC under the benchmark CD measure of marginal cost gives weak estimates of the NPC. To examine whether the incorporation of an open-economy consideration into the marginal cost measures improves the fit of the NPC, we explore an open-economy specification for marginal cost along the lines of Bentolila and Saint-Paul (2001) and Batini, Jackson, and Nickell (2000). The assumption here is that production requires the use of imported raw materials. Therefore, the average marginal cost rises with a rise in real import price ($\frac{P_{mt}}{P_t}$). Specifically, we modify the average marginal cost as

$$\hat{mc^*}^{avg}_{t+j} = \hat{mc}^{avg}_{t+j} + g(\hat{p}_{mt+j} - \hat{p}_{t+j}). \tag{3.7}$$

Table 4 reports the results. In the estimation, we set $g = 0.3$.[24] The coefficient, λ, is positive but still statistically insignificant in the forward-looking specification, as in the benchmark case of the closed economy. Moreover, the results for the hybrid specification give poor estimates of the discount factor.

4. Conclusions

In a sticky-price model, the relative prices are different across firms. This feature implies that the firm-level marginal cost (unobservable) is not necessarily the same as the average aggregate marginal cost (observable). The latter variable is used in the estimation of the NPC. To address this issue, we derived the aggregation factors implied by the model for the cases when firms use CDOL, CES, and CESOL technologies. We estimated the NPC under alternative measures of marginal cost for Canada, the United States, and the euro area. Our results indicate that accounting for the aggregation factors improves the fit of the NPC in terms of the estimated duration of price stickiness. The measures of marginal cost based on CES and CESOL yield better estimates of the NPC relative to the CD cases. For Canada, some of the criticisms of output gap-based NPC apply to a lesser degree relative to the United States and the euro area. Moreover, the hybrid specification gives a larger weight to the backward-looking price-setting behaviour. Finally, the incorporation of open-economy considerations for Canada does not yield better estimates of the NPC. Future work would explore the importance of nominal wage and price rigidities for Canada and the euro area (along the lines of GGL 2001b and Sbordone 2001) in explaining inflation dynamics.

[24] This value of g is the same as when we estimate it along with other parameters.

APPENDIX A:

A.1 Derivation of the optimal pricing rule

The first-order-condition of (2.1) is

$$\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[(\Pi_{k=1}^{j}\pi_{t+k})^{-1}Y_{t+j}\left((1-\epsilon)\left(\frac{P_t^*}{P_{t+j}}\right)^{-\epsilon}\frac{1}{P_{t+j}}+\epsilon\frac{MC_{t,t+j}^n(z)}{P_{t+j}}\left(\frac{P_t^*}{P_{t+j}}\right)^{-\epsilon-1}\frac{1}{P_{t+j}}\right)\right]=0. \tag{A.1}$$

We make use of the fact that $R_{t,t+j}=\beta^j\frac{P_t}{P_{t+j}}=\beta^j(\Pi_{k=1}^{j}\pi_{t+k})^{-1}$. Multiplying (A.1) by P_t^* and dividing by $1-\epsilon$, we get

$$\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[(\Pi_{k=1}^{j}\pi_{t+k})^{-1}Y_{t+j}\left(\left(\frac{P_t^*}{P_{t+j}}\right)^{1-\epsilon}-\mu\frac{MC_{t,t+j}^n(z)}{P_{t+j}}\left(\frac{P_t^*}{P_{t+j}}\right)^{-\epsilon}\right)\right]=0, \tag{A.2}$$

where $\mu=\frac{\epsilon}{\epsilon-1}$ is the steady-state desired markup that would prevail if there were no constraint on pricing behaviour of the firms. Defining $X_t\equiv\frac{P_t^*}{P_t}$ as the optimal relative price, we can write (A.2) as

$$\begin{aligned}\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[(\Pi_{k=1}^{j}\pi_{t+k})^{-1}Y_{t+j}\left(X_t\frac{P_t}{P_{t+j}}\right)^{1-\epsilon}\right]&=\\ \mu\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[(\Pi_{k=1}^{j}\pi_{t+k})^{-1}Y_{t+j}MC_{t,t+j}(z)\left(X_t\frac{P_t}{P_{t+j}}\right)^{-\epsilon}\right]&.\end{aligned} \tag{A.3}$$

The above equation can be written as

$$\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[(\Pi_{k=1}^{j}\pi_{t+k})^{-\epsilon}Y_{t+j}X_t^{(1-\epsilon)}\right]=\mu\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[(\Pi_{k=1}^{j}\pi_{t+k})^{-1-\epsilon}Y_{t+j}MC_{t,t+j}(z)X_t^{-\epsilon}\right]. \tag{A.4}$$

Log-linearizing (A.4) around the flexible price equilibrium values of variables $\{Y_{t+j}\equiv Y^*,\pi_{t+j}=\pi*\equiv 1,X_{t+j}\equiv 1,MC_{t,t+j}(z)\equiv\mu^{-1}\}$ $\forall t,\ \ \forall j$, we get

$$\begin{aligned}Y^*E_t\sum_{j=0}^{\infty}(\theta\beta)^j(\hat{y}_{t+j}+(1-\epsilon)\hat{x}_t+(1+\epsilon-1)\sum_{k=1}^{j}\pi_{t+k})&=\\ Y^*\mu\mu^{-1}E_t\sum_{j=0}^{\infty}\left((1+\epsilon)\sum_{k=1}^{j}\pi_{t+k}+\hat{y}_{t+j}-\epsilon\hat{x}_t+\hat{mc}_{t,t+j}(z)\right)&.\end{aligned} \tag{A.5}$$

After simplifying (A.5) and solving for $\hat{x}_t$, we get

$$\hat{x}_t=(1-\theta\beta)\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[\hat{mc}_{t,t+j}(z)+\sum_{k=1}^{j}\pi_{t+k}\right], \tag{A.6}$$

which is equation (2.2) in section 2.

A.2 Derivation of the aggregation factors

Following Sbordone (2000), we assume that the capital stock of the firm does not change with a change in the relative price of its product.

A.2.1 CDOL

Consider the following CDOL technology:

$$Y_t(z) \equiv F(K_t(z), A_t(N_t(z) - \overline{N})) = K_t(z)^{\alpha}(A_t(N_t(z) - \overline{N}))^{1-\alpha}, \quad 0 < \alpha < 1, \quad \overline{N} > 0. \tag{A.7}$$

The firm-level marginal cost is

$$MC_{t,t+j}(z) = \frac{W_{t+j} N_{t,t+j}(z)}{(1-\alpha) P_{t+j} Y_{t,t+j}(z)} \left[\frac{N_{t,t+j}(z) - \overline{N}}{N_{t,t+j}(z)} \right]. \tag{A.8}$$

The employment in period $t+j$, for a time t price-setting firm, is

$$N_{t,t+j}(z) = \frac{1}{A_{t+j}} \left[\frac{Y_{t,t+j}(z)}{K(z)^{\alpha}} \right]^{\frac{1}{1-\alpha}} + \overline{N}. \tag{A.9}$$

Substituting the demand constraint $Y_{t,t+j}(z) = (\frac{P_t^*}{P_{t+j}})^{-\epsilon} Y_{t+j}$, in (A.9) we can write

$$N_{t,t+j}(z) = \frac{1}{A_{t+j}} \left[\left(\frac{P_t^*}{P_{t+j}} \right)^{-\epsilon} \frac{Y_{t+j}}{K(z)^{\alpha}} \right]^{\frac{1}{1-\alpha}} + \overline{N}. \tag{A.10}$$

The aggregate employment in $t+j$ is defined as

$$N_{t+j} = \frac{1}{A_{t+j}} \left(\frac{Y_{t+j}}{K^{\alpha}} \right)^{\frac{1}{1-\alpha}} + \overline{N}. \tag{A.11}$$

Using (A.11) to substitute $\frac{1}{A_{t+j}} \frac{Y_{t+j}}{K(z)^{\alpha}}$ in (A.10), we get

$$N_{t,t+j}(z) = \left(\frac{P_t^*}{P_{t+j}} \right)^{-\frac{\epsilon}{1-\alpha}} (N_{t+j} - \overline{N}) + \overline{N}. \tag{A.12}$$

Substituting (A.12) and the demand constraint in (A.8), we get

$$MC_{t,t+j}(z) = \underbrace{\frac{W_{t+j} N_{t+j}}{(1-\alpha) P_{t+j} Y_{t+j}} \left(\frac{N_{t+j} - \overline{N}}{N_{t+j}} \right)}_{MC_{t+j}^{avg}} h_{t+j}, \tag{A.13}$$

where

$$h_{t+j} = \frac{N_{t+j}}{N_{t+j} - \overline{N}} \left[\frac{Z_{t+j}^c (N_{t+j} - \overline{N}) + \overline{N}}{Z_{t+j}^d N_{t+j}} \right] \left[\frac{Z_{t+j}^c (N_{t+j} - \overline{N})}{Z_{t+j}^c (N_{t+j} - \overline{N}) + \overline{N}} \right], \tag{A.14}$$

and $Z_{t+j}^c = \left(\frac{P_t^*}{P_{t+j}} \right)^{-\frac{\epsilon}{1-\alpha}}$ and $Z_{t+j}^d = \left(\frac{P_t^*}{P_{t+j}} \right)^{-\epsilon}$.
Equation (A.14) simplifies to

$$h_{t+j} = Z_{t+j}^{c-d} = \left(\frac{P_t^*}{P_{t+j}} \right)^{-\frac{\epsilon\alpha}{1-\alpha}}. \tag{A.15}$$

Therefore, (A.13) is

$$MC_{t,t+j}(z) = \underbrace{\frac{W_{t+j}N_{t+j}}{(1-\alpha)P_{t+j}Y_{t+j}}\left(\frac{N_{t+j}-\overline{N}}{N_{t+j}}\right)}_{MC^{avg}_{t+j}}\left(\frac{P_t^*}{P_{t+j}}\right)^{-\frac{\epsilon\alpha}{1-\alpha}}. \tag{A.16}$$

The log linearization of (A.16) gives

$$\hat{mc}_{t,t+j}(z) = \underbrace{\hat{s}_{t+j} - b\hat{n}_{t+j}}_{\hat{mc}^{avg}_{t+j}} - h^{cdol}\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right); \quad b = \frac{-\overline{N}/N}{1-\overline{N}/N}, \tag{A.17}$$

where the aggregation factor is

$$h^{cdol} = \frac{\epsilon\alpha}{1-\alpha}. \tag{A.18}$$

This expression is the same as for the CD case derived in Sbordone (2000).

A.2.2 CES

Consider the following CES technology:

$$Y_t(z) \equiv F(K_t(z), A_tN_t(z)) = \left[K_t^{\frac{\sigma-1}{\sigma}}(z) + (A_tN_t(z))^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \quad \sigma \neq 1. \tag{A.19}$$

The firm-level marginal cost is

$$MC_{t,t+j}(z) = \frac{W_{t+j}N_{t,t+j}(z)}{\gamma_{t,t+j}P_{t+j}Y_{t,t+j}(z)}, \tag{A.20}$$

where $\gamma_{t,t+j}$ is the firm-level elasticity of output with respect to the labour input. $\gamma_{t,t+j} = A_tN_{t,t+j}\frac{F_N(K(z),A_{t+j}N_{t,t+j}(z))}{F(K(z),A_{t+j}N_{t,t+j}(z))} = \frac{[A_{t+j}N_{t,t+j}(z)]^{1-\frac{1}{\sigma}}}{K^{1-\frac{1}{\sigma}}(z)+[A_{t+j}N_{t,t+j}(z)]^{1-\frac{1}{\sigma}}} = 1 - y_{kt,t+j}^{\frac{1}{\sigma}-1}$, where $y_{kt,t+1} = \frac{Y_{t,t+j}}{K}$. The firm-level employment is given as $N_{t,t+j} = \frac{K(z)}{A_{t+j}}[1-y_{kt,t+j}^{\frac{1}{\sigma}-1}]^{\frac{\sigma}{\sigma-1}}$.
Log linearizing (A.20) gives

$$\hat{mc}_{t,t+j}(z) = \hat{w}_{t+j} + \hat{n}_{t,t+j}(z) - \hat{p}_{t+j} - \hat{y}_{t,t+j} - \hat{\gamma}_{t,t+j}. \tag{A.21}$$

Log linearization of the demand constraint $Y_{t,t+j} = (\frac{P_t^*}{P_{t+j}})^{-\epsilon}Y_{t+j}$ gives

$$\hat{y}_{t,t+j}(z) = -\epsilon\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right) + \hat{y}_{t+j}. \tag{A.22}$$

Our goal is to find expressions for the firm-level variables $\hat{\gamma}_{t,t+j}$ and $\hat{n}_{t,t+j}(z)$ (in (A.21)) in terms of the aggregate variables.

The firm-level elasticity is

$$\gamma_{t,t+j} = 1 - y_{kt,t+j}^{\frac{1}{\sigma}-1}, \tag{A.23}$$

which can be written as

$$\gamma_{t,t+j}y_{kt,t+j}^{1-\frac{1}{\sigma}} = y_{kt,t+j}^{1-\frac{1}{\sigma}} - 1. \tag{A.24}$$

Using (A.24), the firm-level employment can be expressed as

$$N_{t,t+j}(z) = \frac{K(z)}{A_{t+j}}\left[\gamma_{t,t+j}y_{kt,t+j}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}. \tag{A.25}$$

Simplifying (A.25), we get

$$N_{t,t+j}(z) = \frac{K(z)}{A_{t+j}}\left[\gamma_{t,t+j}^{\frac{\sigma-1}{\sigma}}y_{kt,t+j}(z)\right]. \tag{A.26}$$

Log linearization of (A.26) and (A.23) gives (under the assumption $\hat{y}_{kt}(z) = \hat{y}_t(z)$ as $\hat{k}_t(z) = 0$)

$$\hat{n}_{t,t+j}(z) = \frac{\sigma}{\sigma-1}\hat{\gamma}_{t,t+j}(z) + \hat{y}_{t,t+j}(z) - \hat{A}_{t+j}, \tag{A.27}$$

and

$$\hat{\gamma}_{t,t+j} = a\hat{y}_{kt,t+j}(z) = a\hat{y}_{t,t+j}, \quad a \equiv (1-\sigma^{-1})(\mu^{-1}S^{-1}-1), \tag{A.28}$$

Using (A.22), we get

$$\hat{\gamma}_{t,t+j} = \underbrace{a\hat{y}_{t+j}}_{\gamma_{t+j}^{avg}} - a\epsilon\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right). \tag{A.29}$$

Now, the log-linearized expression for the firm-level employment (after substituting (A.29) and (A.22) in (A.27)) is

$$\hat{n}_{t,t+j}(z) = \underbrace{\left(\frac{\sigma a+\sigma-1}{\sigma-1}\right)\hat{y}_{t+j} - \hat{A}_{t+j}}_{\hat{n}_{t+j}} - \left(\frac{a\epsilon\sigma+\epsilon\sigma-\epsilon}{\sigma-1}\right)\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right). \tag{A.30}$$

Substituting (A.22), (A.29), and (A.30) in (A.21), we get

$$\hat{mc}_{t,t+j}(z) = \underbrace{\left(\hat{w}_{t+j} + \hat{n}_{t+j} - \hat{p}_{t+j} - \hat{y}_{t+j} - \hat{\gamma}_{t+j}^{avg}\right)}_{\hat{mc}_{t+j}^{avg}} - \left[\frac{a\epsilon\sigma+\epsilon\sigma-\epsilon}{\sigma-1} - \epsilon - a\epsilon\right]\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right). \tag{A.31}$$

Simplifying (A.31), we get

$$\hat{mc}_{t,t+j}(z) = \underbrace{\left(\hat{s}_{t+j} - \hat{\gamma}_{t+j}^{avg}\right)}_{\hat{mc}_{t+j}^{avg}} - \frac{a\epsilon}{\sigma-1}\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right). \tag{A.32}$$

Since $a \equiv (1-\sigma^{-1})(\mu^{-1}S^{-1}-1)$ and from the calibration restriction (3.1) in the paper, $\alpha = 1-\mu S$, the aggregation factor in this case is

$$h^{ces} = \frac{a\epsilon}{\sigma-1} = \frac{(\sigma-1)(1-\mu S)\epsilon}{\sigma\mu S(\sigma-1)} = \frac{\epsilon\alpha}{\sigma(1-\alpha)}. \tag{A.33}$$

A.2.3 CESOL

Consider the following CESOL technology:

$$Y_t(z) = F(K_t(z), A_t(N_t(z) - \overline{N})) = \left[K_t^{\frac{\sigma-1}{\sigma}}(z) + (A_t(N_t(z) - \overline{N}))^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \quad \sigma \neq 1. \tag{A.34}$$

The firm-level marginal cost is

$$MC_{t,t+j}(z) = \frac{W_{t+j}N_{t,t+j}(z)}{\gamma_{t,t+j}P_{t+j}Y_{t,t+j}(z)}, \tag{A.35}$$

where $\gamma_{t,t+j}$ is the firm-level elasticity of output with respect to the labour input.
Log linearizing (A.35), we get

$$\hat{mc}_{t,t+j}(z) = \hat{w}_{t+j} + \hat{n}_{t,t+j}(z) - \hat{p}_{t+j} - \hat{y}_{t,t+j} - \hat{\gamma}_{t,t+j}. \tag{A.36}$$

Log linearizing the demand constraint $Y_{t,t+j}(z) = (\frac{P_t^*}{P_{t+j}})^{-\epsilon}Y_{t+j}$ gives

$$\hat{y}_{t,t+j}(z) = -\epsilon\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right) + \hat{y}_{t+j}. \tag{A.37}$$

As before, we find expressions for the firm-level variables $\hat{\gamma}_{t,t+j}$ and $\hat{n}_{t,t+j}(z)$ in terms of the aggregates. The firm-level elasticity can be expressed as

$$\gamma_{t,t+j} = \left(\frac{N_{t,t+j}(z)}{N_{t,t+j}(z) - \overline{N}}\right)(1 - y_{kt,t+j}^{\frac{1}{\sigma}-1}). \tag{A.38}$$

Log linearization of (A.38) gives

$$\hat{\gamma}_{t,t+j}(z) = -\left(\frac{\overline{N}}{N - \overline{N}}\right)\hat{n}_{t,t+j} + \frac{1}{\gamma^{cesol}}\hat{y}_{kt,t+j}; \quad \gamma^{cesol} = \mu^{-1}S^{-1}. \tag{A.39}$$

From (A.34) we have

$$N_{t,t+j}(z) - \overline{N} = \frac{\left[Y_{t,t+j}^{\frac{\sigma-1}{\sigma}}(z) - K_t^{\frac{\sigma-1}{\sigma}}(z)\right]^{\frac{\sigma}{\sigma-1}}}{A_{t+j}}. \tag{A.40}$$

Log linearization of (A.40) (assuming $\hat{k}_t = 0$) gives

$$\hat{n}_{t,t+j}(z) = -\left(\frac{N - \overline{N}}{N}\right)\hat{A}_{t+j} + \frac{1}{\gamma^{cesol}}\hat{y}_{kt,t+j}. \tag{A.41}$$

By assumption,

$$\hat{y}_{kt,t+j} = \hat{y}_{t,t+j}. \tag{A.42}$$

Aggregate variables $\{\gamma_{t+j}^{cesol}, N_{t+j}\}$ and their log linearizations are as follows:

$$\gamma_{t+j}^{cesol} = \left(\frac{N_{t+j}}{N_{t+j} - \overline{N}}\right)(1 - y_{kt+j}^{\frac{1}{\sigma}-1}); \quad y_{kt+j} = \frac{Y_{t+j}}{K_t}. \tag{A.43}$$

Log linearization of (A.43) gives

$$\hat{\gamma}_{t+j}^{cesol} = \underbrace{a^{cesol}\hat{y}_{kt+j}}_{\hat{\gamma}_{t+j}^{ces}} - \frac{\overline{N}}{N-\overline{N}}\hat{n}_{t+j}, \tag{A.44}$$

where $a^{cesol} = (1-\sigma^{-1}(\mu^{-1}S^{-1}\frac{N}{N-\overline{N}}-1)$.

$$N_{t+j} - \overline{N} = \frac{\left[Y_{t+j}^{\frac{\sigma-1}{\sigma}}(z) - K_t^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}}{A_{t+j}}. \tag{A.45}$$

Log linearization of (A.45) gives

$$\hat{n}_{t+j} = -\left(\frac{N-\overline{N}}{N}\right)\hat{A}_{t+j} + \frac{1}{\gamma^{cesol}}\hat{y}_{kt+j};\quad \frac{1}{\gamma^{cesol}} = \mu^{-1}S^{-1}. \tag{A.46}$$

Using (A.37) and (A.42), in (A.41) we get

$$\hat{n}_{t,t+j}(z) = \underbrace{-\left(\frac{N-\overline{N}}{N}\right)\hat{A}_{t+j} + \frac{1}{\gamma^{cesol}}\hat{y}_{t+j}}_{\hat{n}_{t+j}} - \frac{\epsilon}{\gamma^{cesol}}\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right). \tag{A.47}$$

Using (A.47) and (A.37) in (A.39), we get

$$\hat{\gamma}_{t,t+j}^{cesol} = \underbrace{-\left(\frac{N}{N-\overline{N}}\right)\left(a^{cesol}\hat{y}_{t+j} + \hat{n}_{t+j}\right)}_{\hat{\gamma}_{t+j}} - \epsilon\left(a^{cesol} - \frac{\overline{N}}{(N-\overline{N})\gamma^{cesol}}\right)\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right). \tag{A.48}$$

After substituting (A.48), (A.47), and (A.37) in (A.36) and simplifying, we get

$$\hat{mc}_{t,t+j}(z) = \underbrace{\hat{w}_{t+j} + \hat{n}_{t+j} - \hat{p}_{t+j} - \hat{y}_{t+j} - \hat{\gamma}_{t+j}}_{\hat{mc}_{t+j}^{avg}} - \underbrace{\epsilon\left[\frac{1}{\gamma^{cesol}} - 1 - a^{cesol} + \frac{\overline{N}}{(N-\overline{N})\gamma^{cesol}}\right]}_{h^{cesol}}\left(\hat{x}_t - \sum_{k=1}^{j}\pi_{t+k}\right), \tag{A.49}$$

where

$$\hat{mc}_{t+j}^{avg} = \hat{s}_{t+j} - a^{cesol}\hat{y}_{t+j} - b\hat{n}_{t+j};\quad b = \frac{-\overline{N}/N}{1-\overline{N}/N}. \tag{A.50}$$

Simplifying h^{cesol} in (A.49), we get

$$h^{cesol} = \epsilon\left[\frac{1}{\gamma^{cesol}} - 1 - a^{cesol} + \frac{\overline{N}}{(N-\overline{N})\gamma^{cesol}}\right]. \tag{A.51}$$

Since $\frac{1}{\gamma^{cesol}} = \mu^{-1}S^{-1}$,

$$h^{cesol} = \epsilon\left[\frac{1}{\mu S} - 1 - \left(\frac{\sigma-1}{\sigma}\right)\left(\frac{\frac{N}{N-\overline{N}} - \mu S}{\mu S} + \frac{\frac{\overline{N}}{N-\overline{N}}}{\mu S}\right)\right]. \tag{A.52}$$

Note that when $\overline{N} = 0$, $h^{cesol} = h^{ces}$.

A.3 Marginal cost-based NPC

Using (2.2), (2.3), and the expression for $\hat{mc}_{t,t+j}(z)$, we derive the NPC as follows:

$$\pi_t = \frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1}{1+h}\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[\hat{mc}_{t+j}^{avg} + (1+h)\sum_{k=1}^{j}\pi_{t+k}\right]. \tag{A.53}$$

We can simplify (A.53) by leading it one period and then premultiplying it by $\theta\beta$. Next, taking $E_t[\ .\ ]$, and subtracting the resulting expression from (A.53), we get

$$\pi_t - \theta\beta E_t\pi_{t+1} = \frac{(1-\theta)(1-\theta\beta)}{\theta}\sum_{j=0}^{\infty}(\theta\beta)^j E_t\left[\left(\hat{mc}_{t+j}^{avg} - \theta\beta\hat{mc}_{t+1+j}^{avg}\right) + (1+h)\sum_{k=1}^{j}(\pi_{t+k} - \theta\beta\pi_{t+1+k})\right]. \tag{A.54}$$

Equation (A.54) can be simplified to

$$\pi_t - \theta\beta E_t\pi_{t+1} = \frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1}{1+h}\hat{mc}_t^{avg} + (1-\theta)\beta E_t\pi_{t+1}. \tag{A.55}$$

From (A.55) we get the NPC

$$\pi_t = \beta E_t\pi_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1}{1+h}\hat{mc}_t^{avg}. \tag{A.56}$$

A.4 Computing the standard errors of estimated λ, $\tilde{\lambda}$, γ_b, γ_f, and D

We use the delta method to compute the standard errors (S.E.) of functions of the structural parameters. For the forward-looking specification,

$$\lambda \equiv \frac{(1-\theta)(1-\theta\beta)}{\theta} \equiv f(\theta,\beta). \tag{A.57}$$

The partial derivatives of (A.57) are evaluated at the estimated values of the structural parameters. These derivatives are $f_\theta(\theta,\beta) = \beta - \frac{1}{\theta^2}$ and $f_\beta(\theta,\beta) = \theta - 1$. Using the estimated variance-covariance matrix, $Var(\lambda)$, we compute

$$Var(\lambda) = [f_\theta \quad f_\beta]\begin{bmatrix} Var(\theta) & Cov(\theta,\beta) \\ & Var(\beta)\end{bmatrix}\begin{bmatrix} f_\theta \\ f_\beta\end{bmatrix},$$

and obtain the S.E.(λ). Similarly, for the hybrid NPC,

$$\tilde{\lambda} \equiv (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1} \equiv f(\theta,\beta,\omega), \tag{A.58}$$

where $\phi \equiv \theta + \omega[1-\theta(1-\beta)]$.
The partial derivatives of (A.58) evaluated at the estimated values of the structural parameters are

$$f_\theta = \frac{-(1-\omega)(1+\beta-2\theta\beta)(\theta+\omega(1-\theta(1-\beta))) - ((1-\omega)(1-\theta)(1-\beta\theta)(1-\omega(1-\beta)))}{(\theta+\omega(1-\theta(1-\beta)))^2},\ f_\beta = \frac{-\theta(1-\omega)(1-\theta)(\theta(1-\omega)+2\omega)}{(\theta+\omega(1-\theta(1-\beta)))^2},$$

and $f_\omega = \frac{-(1-\theta)(1-\beta^2\theta^2)}{(\theta+\omega(1-\theta(1-\beta)))^2}$. Using the estimated variance-covariance matrix, $Var(\tilde{\lambda})$, we compute

$$Var(\tilde{\lambda}) = [f_\theta \quad f_\beta \quad f_\omega] \begin{bmatrix} Var(\theta) & Cov(\theta,\beta) & Cov(\theta,\omega)) \\ & Var(\beta) & Cov(\omega,\beta) \\ & & Var(\omega) \end{bmatrix} \begin{bmatrix} f_\theta \\ f_\beta \\ f_\omega \end{bmatrix},$$

and obtain the SE($\tilde{\lambda}$). For other functions of structural parameters, γ_b, γ_f, and D, we follow the same procedure. $\gamma_b \equiv \omega\phi^{-1} \equiv f(\theta,\beta,\omega)$ with partial derivatives $f_\theta = \frac{-\omega(1-\omega(1-\beta))}{\theta+\omega(1-\theta(1-\beta))^2}$, $f_\beta = \frac{-\theta\omega^2}{\theta+\omega(1-\theta(1-\beta))^2}$, and $f_\omega = \frac{\theta}{\theta+\omega(1-\theta(1-\beta))^2}$. Using these derivatives in $Var(\tilde{\lambda})$ gives the SE(γ_b). $\gamma_f \equiv \beta\theta\phi^{-1} \equiv f(\theta,\beta,\omega)$ with partial derivatives $f_\theta = \frac{\beta\omega}{(\theta+\omega(1-\theta(1-\beta))^2}$, $f_\beta = \frac{\theta(1+\omega(1-\theta))}{(\theta+\omega(1-\theta(1-\beta))^2}$, and $f_\omega = \frac{-\beta\theta(1-\theta+\beta\theta)}{(\theta+\omega(1-\theta(1-\beta))^2}$. Using these derivatives in $Var(\tilde{\lambda})$ gives the SE(γ_f). Finally, $D = \frac{1}{1-\theta}$ and SE$(D) = \frac{1}{(1-\theta)^2}SE(\theta)$.

Using the standard errors, we obtain the p-values reported in the tables.

Appendix B: Data Description

B.1 Definition of the variables

All data are quarterly time series. Any monthly data are converted to quarterly frequency.

Output gap is the deviation of real GDP ($y_t = \ln Y_t$) from its steady state, approximated by a quadratic trend: $\hat{y}_t = 100(y_t - \bar{y}_t)$.
Price inflation is the quarterly growth rate of the total GDP deflator: $\pi_t = 100(\ln P_t \text{ -}\ln P_{t-1})$.
Wage inflation is the quarterly growth rate of compensation of employees: $w_t = 100(\ln W_t$-$\ln W_{t-1})$.
Labour income share is the ratio of total compensation and nominal GDP: $s_t = \ln S_t$ and $\hat{s}_t = 100(s_t - s)$ (the labour income share in deviation from its steady-state), where $s = \ln S$ and $S = \frac{\sum_t^T ln(S_t)}{T}$.
Average real marginal costs are

1. CD: $\hat{mc}_t^{avg} = \hat{s}_t$.
2. CDOL: $\hat{mc}_t^{avg} = \hat{s}_t - b\hat{n}_t$.
3. CES: $\hat{mc}_t^{avg} = \hat{s}_t - a\hat{y}_t$.
4. CESOL: $\hat{mc}_t^{avg} = \hat{s}_t - a^{cesol}\hat{y}_t - b\hat{n}_t$.

Labour is total employment, $n_t = \ln N_t$, and $\hat{n}_t$ is the deviation from the quadratic trend: $\hat{n}_t = 100(n_t - \bar{n}_t)$.
Output-capital ratio is the ratio of real GDP to capital stock, $yk_t = \ln\frac{Y_t}{K_t}$, and $\hat{yk}_t$ is the deviation from the quadratic trend: $\hat{yk}_t = 100(yk_t - \bar{yk}_t)$.

B.2 Data sources, series labels, and sample periods

The data for Canada are from Statistics Canada's database. The data for the United States are from the Bureau of Labour Statistics (BLS) and the Bureau of Economic Analysis (BEA). For the euro area, we use the data from the European Central Bank (see Fagan, Henry, and Mestre 2001).

Variable	Canada	United States	Euro area
P_t	$D15612$	$\frac{Q.GDP}{Q.GDP96c}$	YED
Y_t	$I56001 - I56013 - I56018$	$Q.JQNF$	YER
N_t	$LFSA201$: 1970:1-1975:4 $D980595$: 1976:1-2000:4	$M.EEA$	LNN
W_t	$\frac{D17023}{N_t}$	$Q.JRWSSNF$	$\frac{WIN}{LNN}$
K_t	$KBUS$	$Q.KNIFIXR92C$	KSR
S_t	$\frac{D17023-D17001}{D15612*Y_t}$	$\frac{\frac{W_t}{Q.JQ\%MHNF}}{Q.PNF}$	$\frac{WIN}{YEN}$

Canada: 1970Q1 to 2000Q4

Total labour income = $D17023$
Farm (agriculture + fishing & trapping) labour income = $D17001$
Total GDP deflator = $D15612$
Total real GDP = $I56001$
Farm GDP = $I56013$ (agriculture) + $I56018$ (fishing & trapping)
Employment, "total employed persons" = [$LFSA201$ (1970Q1 to 1975Q4) and $D980595$ (1976Q1 to 2000Q4)]
Total import price (P_{mt}) = B1226
Capital stock = $KBUS$

United States: 1970Q1 to 2001Q1

Implicit price deflator, non-farm business sector (NFB) = $Q.PNF$
Employment (persons) (NFB) = $M.EEA$
Real GDP (NFB) = $Q.JQNF$
Total nominal GDP = $Q.GDP$
Total real GDP = $Q.GDP96c$
Wage (compensation per hour) (NFB) = $Q.JRWSSNF$
Productivity per hour (NFB) = $Q.JQ\%MHNF$
Capital stock = $Q.KNIFIXR92c$

Euro area: 1970Q1 to 1998Q4

Total compensation = WIN
Nominal GDP = YEN
Real GDP = YER
Total GDP deflator = YED
Total number of employees = LNN
Capital stock = KSR

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Table 1: Parameters							
Calibrated				*Aggregation factors*			
	S	μ	σ	$\frac{1}{1+h}^{cd}$	$\frac{1}{1+h}^{cdol}$	$\frac{1}{1+h}^{ces}$	$\frac{1}{1+h}^{cesol}$
Canada	0.56	1.1	0.5	0.13	0.13	0.07	0.05
U.S.	0.66	1.1	0.5	0.20	0.20	0.11	0.07
Euro area	0.75	1.1	0.5	0.30	0.30	0.17	0.11

Table 2: Reduced-form estimates of new Phillips curve: *output gap-based*

	β	κ	γ_b	γ_f	J-statistic
1. Canada	0.959	0.007	-	-	9.65
	(0.00)	(0.41)	-	-	(0.78)
	-	0.006	0.327	0.642	6.77
	-	(0.29)	(0.00)	(0.00)	(0.91)
2. U.S.	1.000	-0.011	-	-	7.31
	(0.00)	(0.00)	-	-	(0.92)
	-	-0.001	0.373	0.623	7.41
	-	(0.69)	(0.00)	(0.00)	(0.88)
3. Euro area	0.991	-0.004	-	-	8.94
	(0.00)	(0.54)	-	-	(0.83)
	-	0.007	0.269	0.718	7.86
	-	(0.23)	(0.00)	(0.00)	(0.85)

Sample period: Canada 1970Q1 to 2000:4, U.S. 1970Q1 to 2001Q1, euro area 1970Q1 to 1998Q4.

The p-value is in brackets.

The J-statistics is used to test for overidentifying restrictions.

Table 3a: Structural estimates of new Phillips curve for Canada (closed economy)									
Technology	$\frac{1}{1+h}$	θ	β	λ	ω	γ_b	γ_f	D	J-statistic
1. CD	1	0.928	0.954	0.008	-	-	-	13.9	8.92
		(0.00)	(0.00)	(0.35)	-	-	-	(0.00)	(0.96)
		0.857	0.803	0.011	0.649	0.464	0.492	7.0	8.98
		(0.00)	(0.00)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
	0.13	0.786	0.954	0.067	-	-	-	4.6	8.92
		(0.00)	(0.00)	(0.35)	-	-	-	(0.00)	(0.96)
		0.616	0.854	0.085	0.496	0.464	0.492	2.6	8.99
		(0.00)	(0.00)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
2. CDOL	1	0.916	0.945	0.012	-	-	-	11.9	8.81
		(0.00)	(0.00)	(0.21)	-	-	-	(0.00)	(0.96)
		0.853	0.778	0.013	0.632	0.463	0.486	6.8	9.01
		(0.00)	(0.00)	(0.06)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
	0.13	0.752	0.945	0.095	-	-	-	4.0	8.80
		(0.00)	(0.00)	(0.21)	-	-	-	(0.00)	(0.96)
		0.600	0.833	0.102	0.475	0.463	0.486	2.5	9.01
		(0.00)	(0.00)	(0.06)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
3. CES	1	0.909	0.920	0.002	-	-	-	10.9	8.83
		(0.00)	(0.00)	(0.09)	-	-	-	(0.00)	(0.96)
		0.855	0.733	0.016	0.601	0.455	0.475	6.9	9.32
		(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.92)
	0.07	0.635	0.920	0.238	-	-	-	2.7	8.83
		(0.00)	(0.00)	(0.09)	-	-	-	(0.00)	(0.96)
		0.485	0.811	0.236	0.377	0.455	0.475	1.9	9.32
		(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.92)
4. CESOL	1	0.917	0.918	0.014	-	-	-	12.0	8.84
		(0.00)	(0.00)	(0.06)	-	-	-	(0.00)	(0.96)
		0.879	0.762	0.011	0.600	0.443	0.495	8.3	9.43
		(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.92)
	0.05	0.598	0.918	0.304	-	-	-	2.5	8.84
		(0.00)	(0.00)	(0.06)	-	-	-	(0.00)	(0.96)
		0.477	0.837	0.250	0.358	0.443	0.495	1.9	9.43
		(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.92)

The p-value is in brackets. D is the estimated duration of price stickiness.

Table 3b: Structural estimates of new Phillips curve for the United States									
Technology	$\frac{1}{1+h}$	θ	β	λ	ω	γ_b	γ_f	D	J-statistic
1. CD	1	0.900	0.914	0.019	-	-	-	10.0	10.00
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.876	0.885	0.009	0.523	0.388	0.576	8.0	6.88
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)
	0.20	0.758	0.914	0.097	-	-	-	4.1	10.00
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.719	0.901	0.049	0.437	0.388	0.576	3.6	6.88
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)
2. CDOL	1	0.900	0.915	0.019	-	-	-	10.0	10.01
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.875	0.886	0.010	0.523	0.388	0.576	8.01	6.87
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)
	0.20	0.757	0.915	0.097	-	-	-	4.1	10.02
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.718	0.901	0.049	0.437	0.388	0.576	3.5	6.87
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.09)	(0.91)
3. CES	1	0.901	0.914	0.019	-	-	-	10.1	9.95
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.875	0.883	0.009	0.523	0.389	0.574	8.0	6.88
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)
	0.11	0.683	0.914	0.173	-	-	-	3.1	9.95
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.642	0.905	0.089	0.393	0.389	0.574	2.8	6.88
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)
4. CESOL	1	0.900	0.915	0.019	-	-	-	10.0	9.96
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.875	0.883	0.010	0.523	0.389	0.574	8.0	6.88
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)
	0.07	0.648	0.915	0.219	-	-	-	2.8	9.96
		(0.00)	(0.00)	(0.01)	-	-	-	(0.00)	(0.76)
		0.607	0.908	0.114	0.374	0.389	0.574	2.5	6.88
		(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.91)

The p-value is in brackets. D is the estimated duration of price stickiness.

Table 3c: Structural estimates of new Phillips curve for the euro area									
Technology	$\frac{1}{1+h}$	θ	β	λ	ω	γ_b	γ_f	D	J-statistic
1. CD	1	0.919	0.920	0.013	-	-	-	12.3	9.44
		(0.00)	(0.00)	(0.02)	-	-	-	(0.00)	(0.80)
		0.918	0.908	0.008	0.287	0.243	0.705	12.2	8.44
		(0.00)	(0.00)	(0.17)	(0.00)	(0.00)	(0.00)	(0.00)	(0.81)
	0.30	0.836	0.920	0.044	-	-	-	6.1	9.44
		(0.00)	(0.00)	(0.02)	-	-	-	(0.00)	(0.80)
		0.833	0.910	0.027	0.261	0.243	0.705	6.0	8.44
		(0.00)	(0.00)	(0.17)	(0.00)	(0.00)	(0.00)	(0.00)	(0.81)
2. CDOL	1	0.919	0.919	0.013	-	-	-	12.4	9.45
		(0.00)	(0.00)	(0.04)	-	-	-	(0.00)	(0.80)
		0.917	0.904	0.008	0.288	0.244	0.703	12.0	8.45
		(0.00)	(0.00)	(0.18)	(0.00)	(0.00)	(0.00)	(0.00)	(0.81)
	0.30	0.836	0.920	0.045	-	-	-	6.1	9.45
		(0.00)	(0.00)	(0.04)	-	-	-	(0.00)	(0.80)
		0.831	0.907	0.029	0.262	0.244	0.703	5.9	8.45
		(0.00)	(0.00)	(0.18)	(0.00)	(0.00)	(0.00)	(0.00)	(0.81)
3. CES	1	0.916	0.908	0.015	-	-	-	11.9	9.47
		(0.00)	(0.00)	(0.02)	-	-	-	(0.00)	(0.80)
		0.909	0.877	0.011	0.280	0.241	0.689	11.0	8.64
		(0.00)	(0.00)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)	(0.80)
	0.18	0.773	0.908	0.087	-	-	-	4.4	9.47
		(0.00)	(0.00)	(0.02)	-	-	-	(0.00)	(0.80)
		0.754	0.883	0.065	0.233	0.241	0.688	4.0	8.64
		(0.00)	(0.00)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)	(0.80)
4. CESOL	1	0.916	0.903	0.016	-	-	-	11.9	9.47
		(0.00)	(0.04)	(0.07)	-	-	-	(0.00)	(0.80)
		0.903	0.845	0.014	0.279	0.244	0.668	10.3	8.83
		(0.00)	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.78)
	0.11	0.710	0.903	0.147	-	-	-	3.4	9.47
		(0.00)	(0.00)	(0.04)	-	-	-	(0.00)	(0.80)
		0.663	0.857	0.135	0.208	0.244	0.667	3.0	8.83
		(0.00)	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.78S)

The p-value is in brackets. D is the estimated duration of price stickiness.

Table 4: Structural estimates of new Phillips curve for Canada (open economy)									
Technology	$\frac{1}{1+h}$	θ	β	λ	ω	γ_b	γ_f	D	J-statistic
1. CD	1	0.941	0.909	0.009	-	-	-	17.1	9.05
		(0.00)	(0.00)	(0.29)	-	-	-	(0.00)	(0.96)
		0.914	0.701	0.010	0.564	0.426	0.484	11.67	9.28
		(0.00)	(0.00)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.93)
	0.13	0.798	0.901	0.069	-	-	-	4.9	9.05
		(0.00)	(0.00)	(0.29)	-	-	-	(0.00)	(0.96)
		0.688	0.746	0.078	0.452	0.426	0.484	3.21	9.28
		(0.00)	(0.00)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.93)
2. CDOL	1	0.934	0.871	0.013	-	-	-	15.1	8.75
		(0.00)	(0.00)	(0.14)	-	-	-	(0.00)	(0.96)
		0.912	0.664	0.012	0.541	0.420	0.470	11.4	9.14
		(0.00)	(0.00)	(0.06)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
	0.13	0.765	0.871	0.102	-	-	-	4.3	8.75
		(0.00)	(0.00)	(0.14)	-	-	-	(0.00)	(0.96)
		0.675	0.711	0.095	0.428	0.420	0.470	3.1	9.14
		(0.00)	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
3. CES	1	0.933	0.839	0.015	-	-	-	15.0	9.21
		(0.00)	(0.00)	(0.12)	-	-	-	(0.00)	(0.95)
		0.911	0.486	0.020	0.516	0.435	0.374	11.2	9.08
		(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
	0.07	0.665	0.839	0.222	-	-	-	3.0	9.21
		(0.00)	(0.00)	(0.12)	-	-	-	(0.00)	(0.95)
		0.515	0.564	0.292	0.338	0.435	0.373	2.0	9.08
		(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
4. CESOL	1	0.933	0.800	0.018	-	-	-	15.0	9.07
		(0.00)	(0.00)	(0.05)	-	-	-	(0.00)	(0.96)
		0.914	0.472	0.021	0.491	0.420	0.370	11.7	8.90
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)
	0.05	0.582	0.799	0.384	-	-	-	2.4	9.07
		(0.00)	(0.00)	(0.05)	-	-	-	(0.00)	(0.96)
		0.473	0.559	0.448	0.281	0.420	0.369	1.8	8.90
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.94)

The p-value is in brackets. D is the estimated duration of price stickiness.

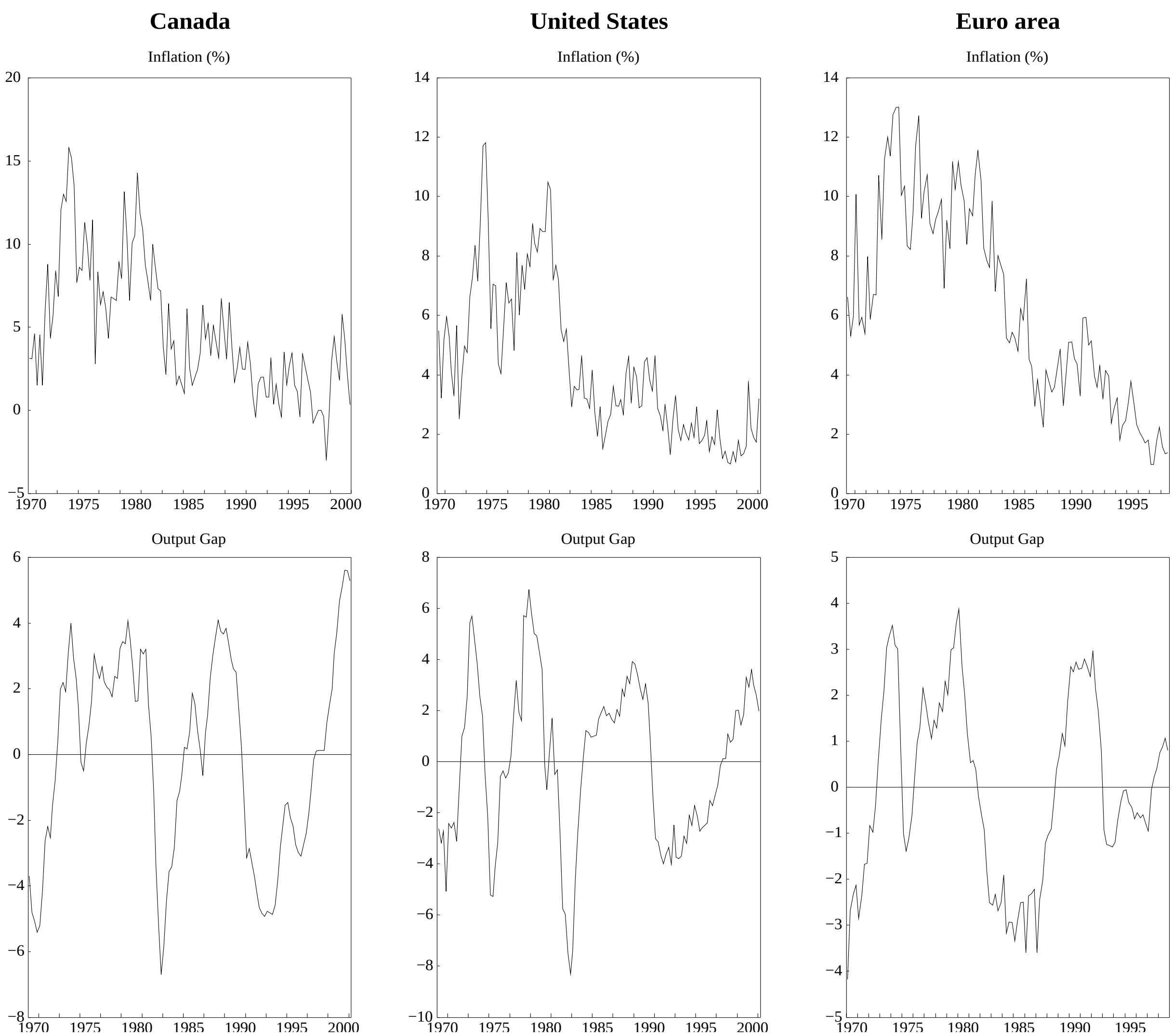

Figure 1: Annualized (price) inflation ($4\pi_t$), output gap ($\hat{y}_t$)

Figure 2: Alternative marginal cost measures ($\hat{mc}_t^{avg}$)

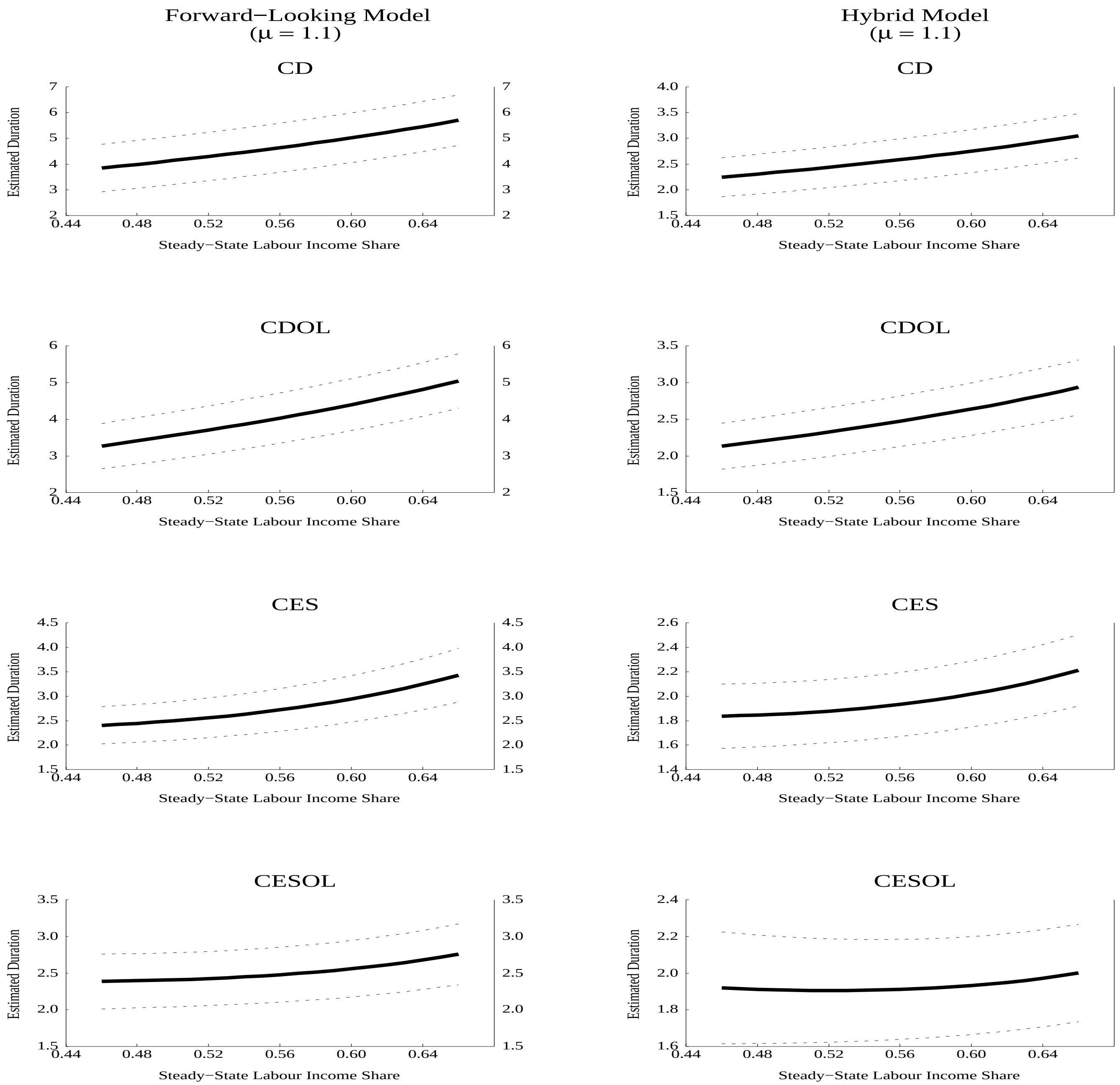

Figure 3: Canada: Estimated duration and steady-state labour share

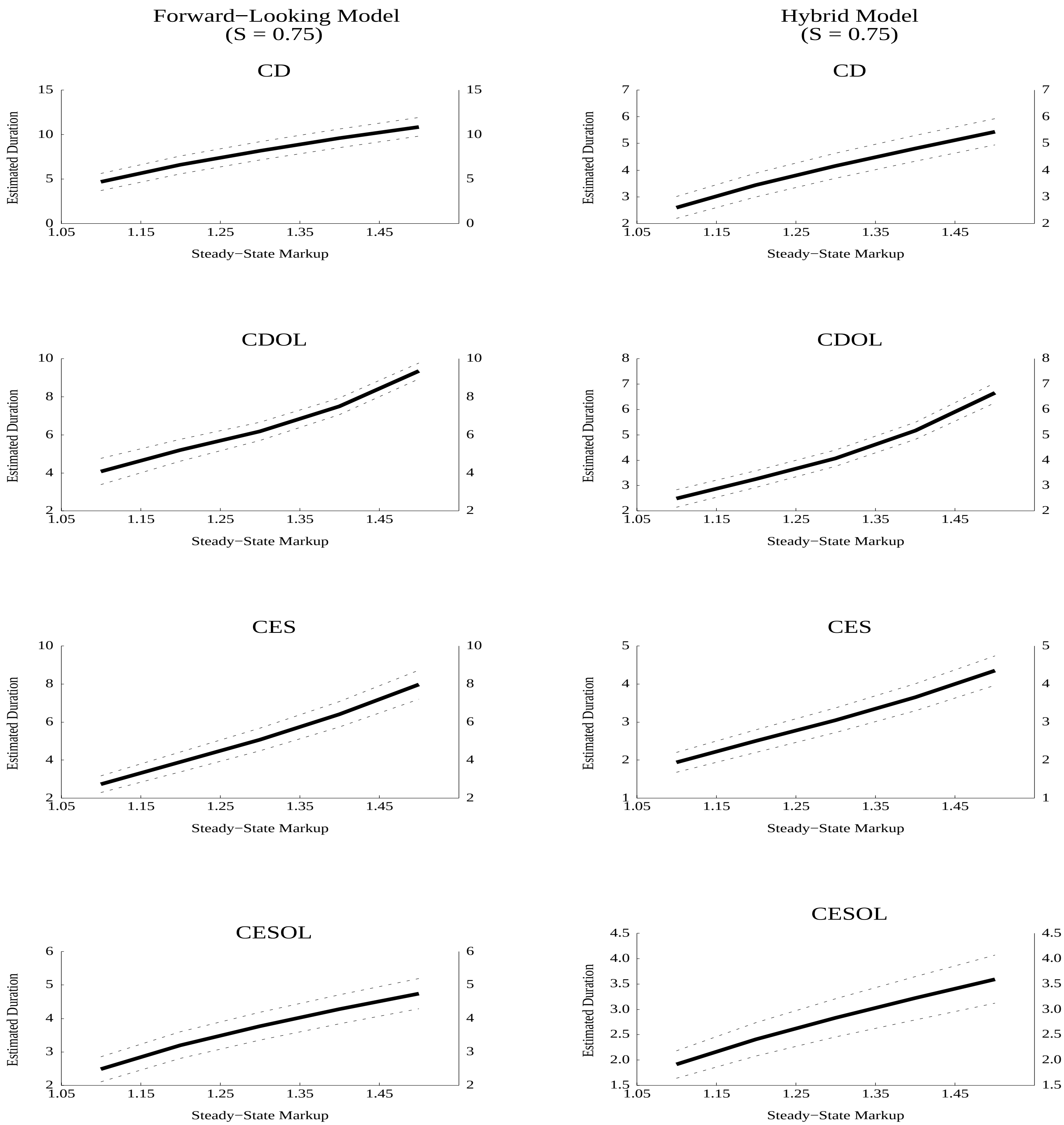

Figure 4: Canada: Estimated duration and steady-state markup

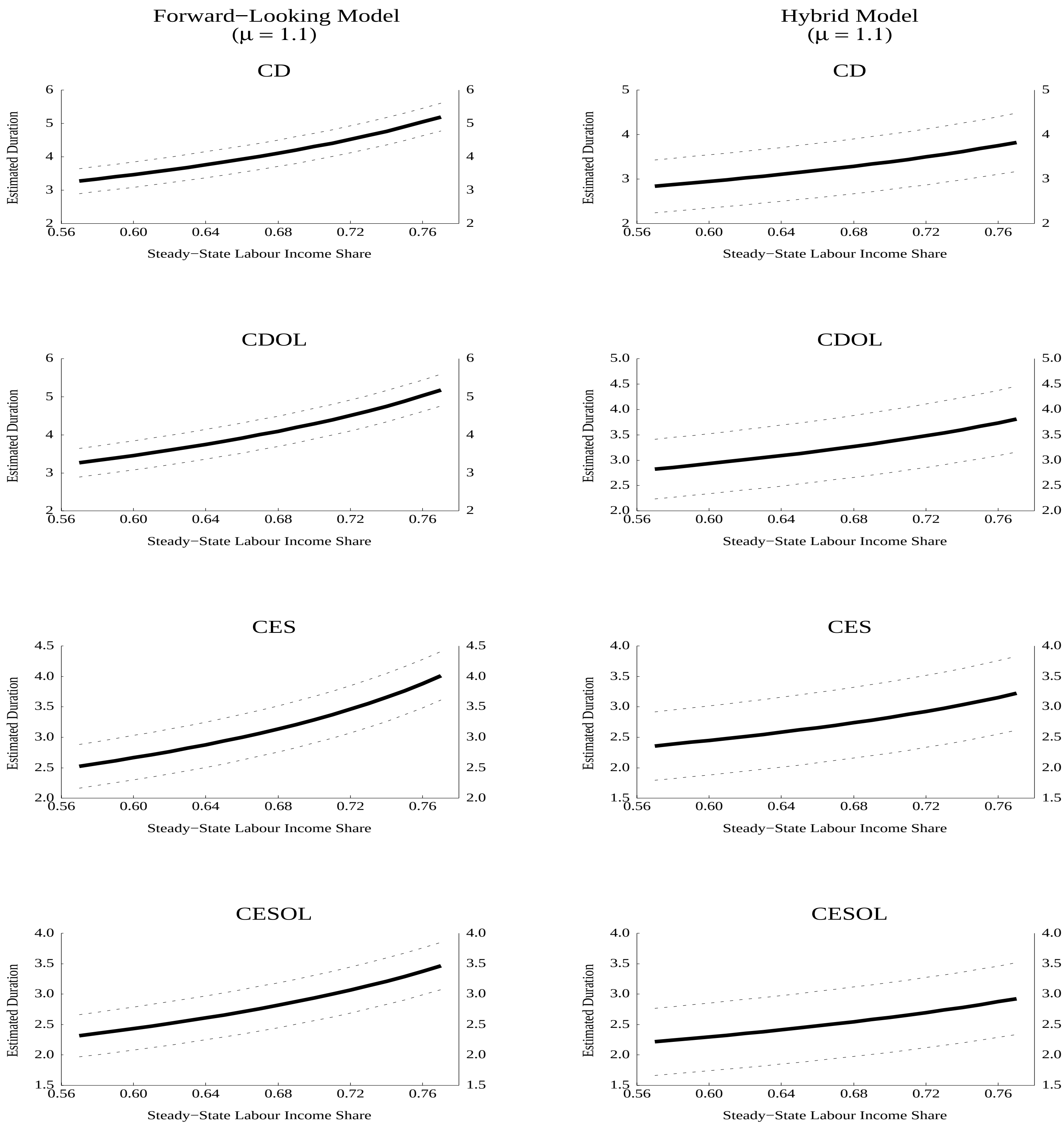

Figure 5: United States.: Estimated duration and steady-state labour share

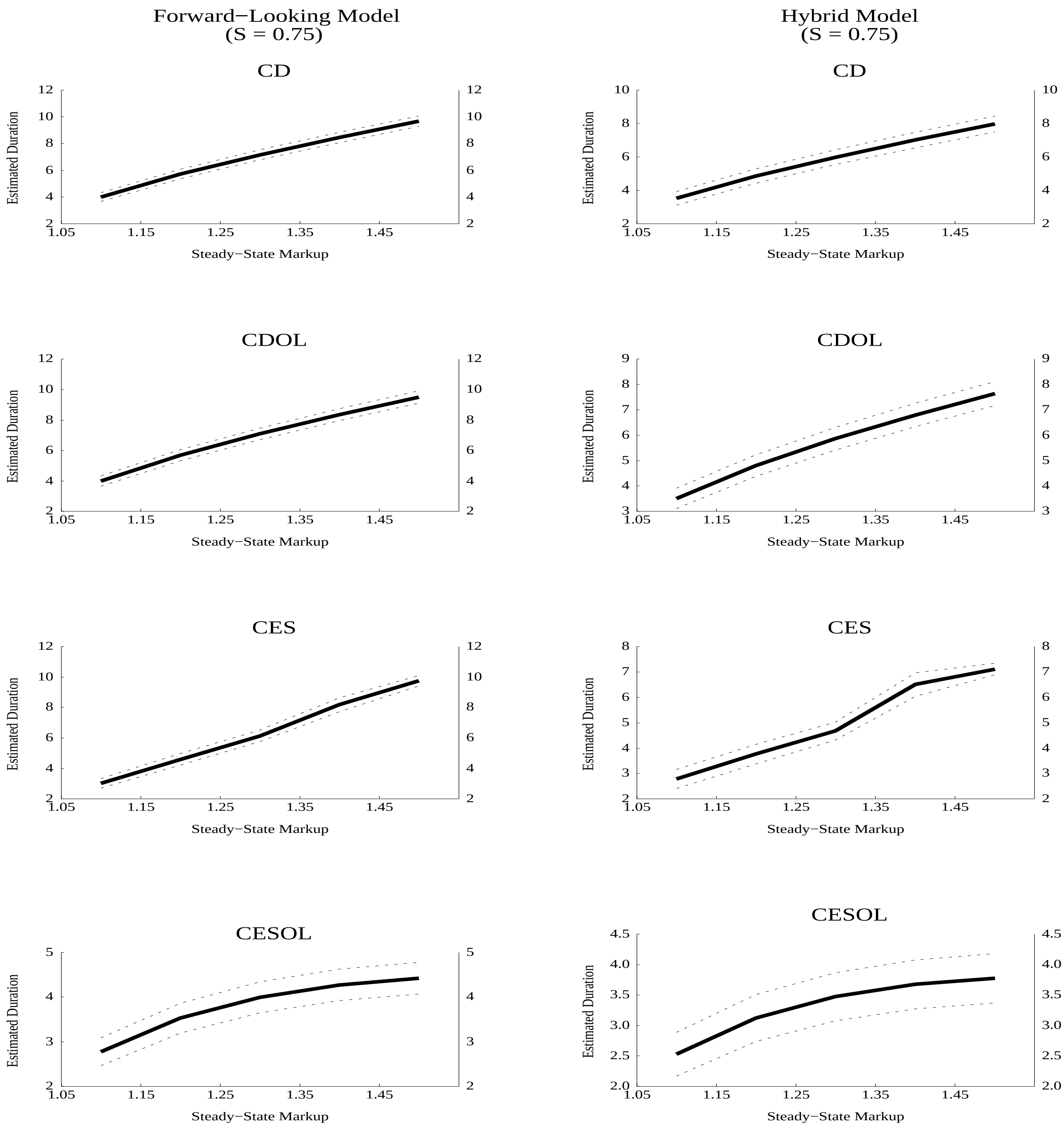

Figure 6: United States: Estimated duration and steady-state markup

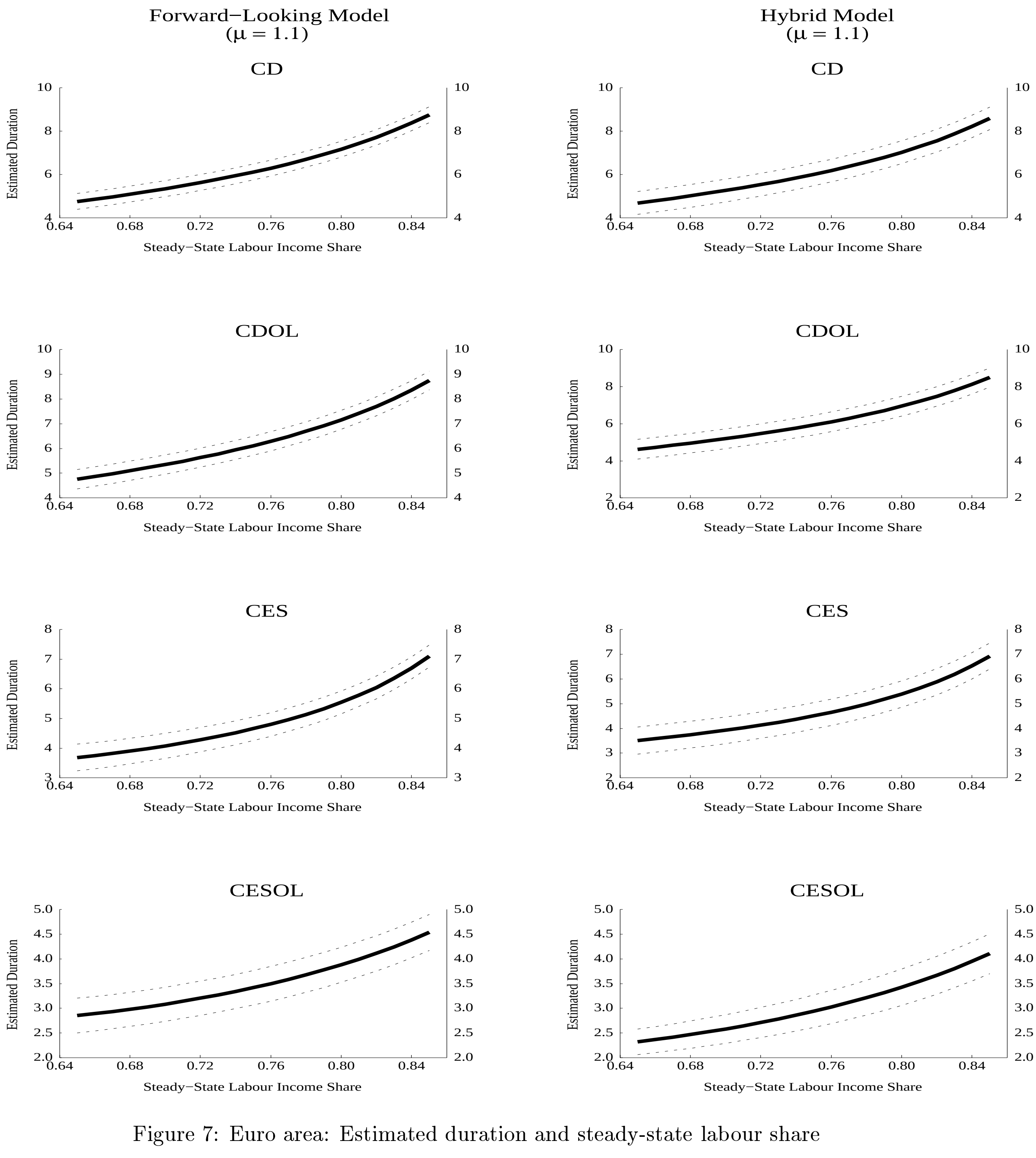

Figure 7: Euro area: Estimated duration and steady-state labour share

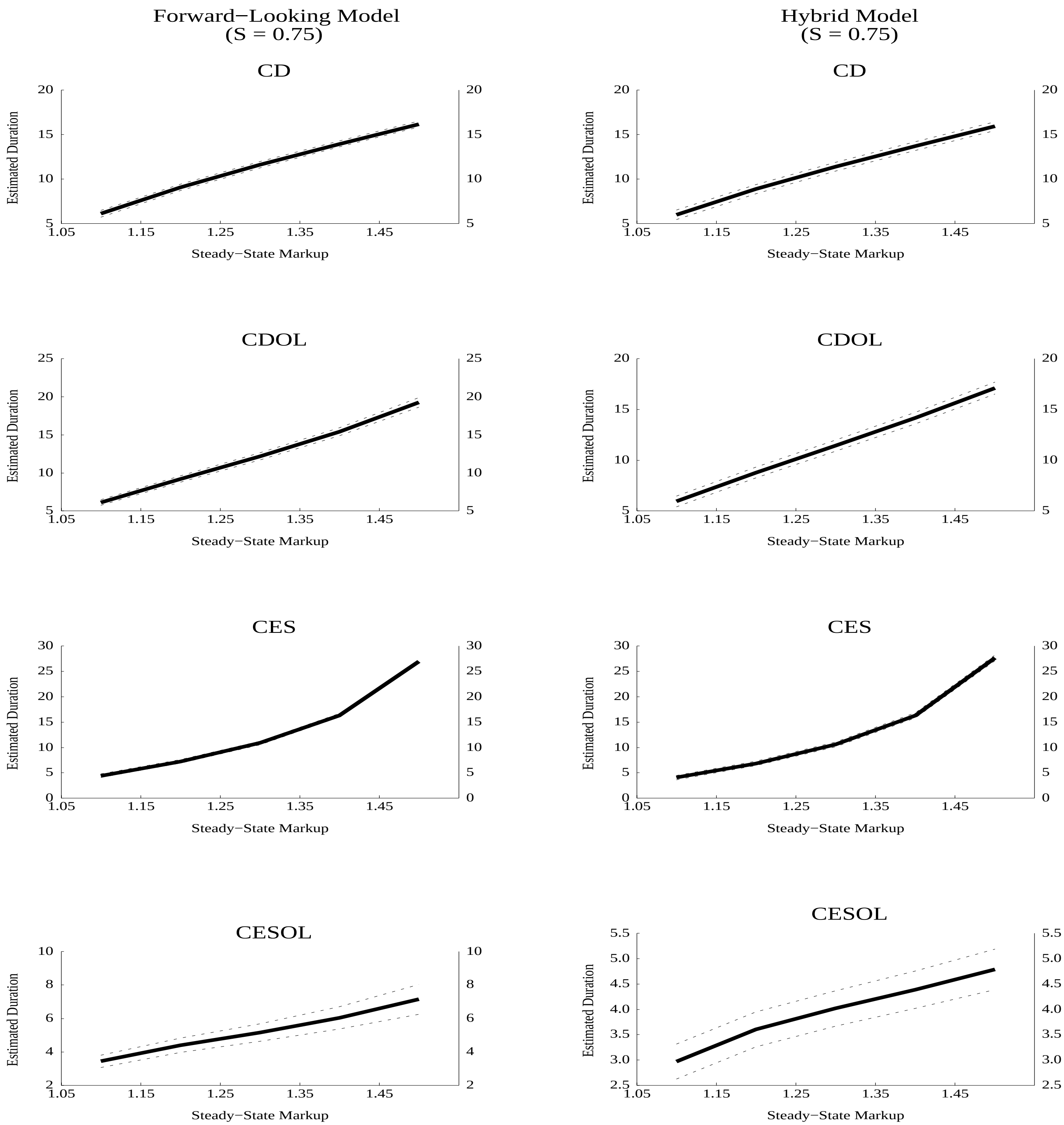

Figure 8: Euro area: Estimated duration and steady-state markup

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