Inflation persistence: Implications for a design of monetary policy in a small open economy subject to external shocks

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Abstract

We analyze implications of inflation persistence for business cycle dynamics following terms of trade and risk-premium shocks in a small open economy, under fixed and flexible exchange rate regimes. We show that the country's adjustment paths are slow and cyclical if there is a significant backward-looking element in the inflation dynamics and the exchange rate is fixed. We also show that such cyclical adjustment paths are moderated if there is a high proportion of forward-looking price setters. In contrast, with an independent monetary policy, flexible exchange rate allows to escape severe cycles, supporting the conventional wisdom about the insulation role of flexible exchange rates.

JEL Classifications: E32, F40, F41

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1 Introduction

The debate regarding the choice of an exchange rate regime is very old, and yet it remains to be controversial. The theoretical literature provides broad guidance on the choice of exchange rate. Much of the modern analysis of choosing an exchange rate regime goes back to the works of Friedman (1953), Mundell (1963) and Fleming (1962). Friedman (1953) made the modern case for a flexible exchange rate: a flexible exchange rate is desirable in the face of real country-specific shocks that require adjustment in relative prices between countries, because nominal prices are highly inflexible. However, if prices are flexible, the choice of exchange rate is irrelevant as adjustment in relative prices can happen either via changes in the nominal exchange rate or prices.

Friedman's analysis has been extended by Mundell (1963) and Fleming (1962) to a world of capital mobility[1]. Following their work, one of an important considerations in the choosing of an exchange rate regime have become the nature and source of the shocks to the economy and the degree of capital mobility. In general, a fixed exchange rate in an open economy with capital mobility is preferable if the shocks buffeting the economy are predominantly monetary,

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[1]See Bordo (2003) for survey of the issues relating to exchange rate regime choice in historical perspective.

such as changes in the demand for money. A flexible exchange rate is preferable if shocks are predominantly real, such as changes in technology or tastes[2].

The emergence of an important strand of macroeconomics, called New Open Economy Macro-economics (NOEM)[3], enabled analysis of the design of monetary policy and the choice of exchange rate in an open economy within stochastic, sticky-price general equilibrium optimizing models. General equilibrium sticky-models, based on utility maximization, allow to examine welfare consequences of alternative monetary rules. Now there is a lengthy literature that studies the performance of monetary rules (optimal or not) in open economies[4]. From traditional NOEM models the general consensus has emerged that countries should allow their exchange rates to float freely and use monetary policy to target some measure of inflation.

Despite the insulating role of flexible exchange rates in open-economies in the face of real shocks, greater fixity of exchange rate may be justified on many grounds. For example, in many small open economies exports, imports and international capital flows represent a large share of their economies, so large variations in the exchange rate can cause very large variations in the real economy. Another argument in favor of greater fixity of the exchange rate is the *liability dollarization* – phenomenon, which is characterized by external net liabilities denominated in dollars and revenues generated in local currency. In this case, a sharp real exchange rate depreciation causes a decline in the net worth of corporations and individuals, leading to a sharp decline in lending and hence economic contraction. This situation can be exacerbated in the presence of financial imperfections, which can arise from informational asymmetries or institutional shortcomings, and which imply that borrowers face constraints. In this case, the contractionary effect of an exchange rate depreciation works through the negative financial accelerator channel, which links the condition of the borrower's balance sheets with the terms of credit. A sharp depreciation, which reduces earnings of firms and deteriorates their balance sheets, decreases firms' capacities to borrow and invest. This discussion suggests that financial vulnerability is a sufficient reason for abandoning a floating exchange rate in favor of a more fixed rate. However, a number of papers that incorporate the financial accelerator mechanism in general equilibrium setting with nominal rigidities (e.g., Céspedes et al., (2000), Gertler et al. (2003), Devereux et al. (2004)) claim that the presence of such financial frictions amplify the business cycle, but do not alter conventional wisdom that flexible exchange rate are less contractionary than fixed rates and flexible exchange rates are optimal from a welfare point of view.

One feature that characterizes most of the models discussed above is the entirely forward-

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[2] When shocks come from the money market, a country benefits from a fixed-rate regime. The shock would be absorbed through purchases and sales of foreign exchange by the monetary authority, which would affect the money supply, maintain a fixed exchange rate, and keep real output unaffected. With sticky wages and prices, countries that are subject to real shocks are better off with a flexible exchange rate. In the face of negative real shocks, a depreciation of the exchange rate would reduce the price of tradable goods and ensure expenditure switching from more expensive foreign goods to relatively cheaper domestically produced goods, and thus offset the negative effect of the shock.

[3] Literature survey, see Lane (2001)

[4] Aoki (2001), Galí and Monacelli (2002), Ghironi and Rebucci (2001), Parrado and Velasco (2001), among others

looking nature of price setting behavior[5]. The models of these papers specify nominal rigidities by assuming a time-contingent staggered Calvo (1983) price setting mechanism that generates a standard forward-looking New Keynesian Phillips Curve (NKPC)[6]. The forward-looking nature of the NKPC, in turn, implies a great deal of flexibility for the dynamics of inflation. This, however, is in contrast with empirical evidence, which suggests that inflation is highly persistent[7]. In this paper we develop a dynamic general equilibrium small open-economy model, where inflation persistence is incorporated via introduction of rule-of-thumb price setting. We use this model to study the effects of such backward-looking behavior on dynamic adjustment in response to the shocks. The paper aims to explore the implications of inflation inertia for business cycle dynamics in the face of terms of trade and risk-premium shocks. In our framework, nominal and real exchange rates play a central role in the adjustment process when prices are sticky. Therefore, our discussion focuses on the question of the insulating properties of alternative exchange rate regimes. We study two commonly-used monetary policies: a fixed exchange rate (when the monetary authority stabilizes the nominal exchange rate) and a flexible exchange rate (when the central bank stabilizes inflation).

Our paper is related to two strands of the literature. The first is one that studies performance of simple monetary rules (whether optimal or not) in a dynamic New Keynesian framework, briefly discussed above. The second focuses on empirical evidence of inflation persistence, its determinants and implications for a design of monetary policy.

As we have noted earlier, most of the papers within the literature on the performance of monetary rules in open economies focus on a standard forward-looking Phillips curve that exhibits no intrinsic persistence. However, there are many more models that incorporate inflation persistence into stochastic general equilibrium settings with nominal rigidities to study different issues (e.g., Christiano et al. (2001), Leitemo (2002), Benigno and Thoenissen (2003), Smets and Wouters (2002)). Our paper is probably closest to Leitemo (2002), who analyzes the insulating role of alternative monetary policy regimes for different degrees of inflation persistence. Contrary to our paper, Leitemo illustrates the significance of different monetary policy regimes, both for a reduction of volatility in key macro variables in the face of shocks and for welfare (we, however, do not look at welfare). In particular, Leitemo finds that social loss under different monetary regimes is lower when there is less inflation persistence, and perhaps the most important finding is that the currency-board arrangement (as well as the exchange-rate targeting regime) achieves the greatest improvement in terms of a social loss as inflation becomes more forward-looking. However, it is important to note that, his model is a one-sector model, which embodies some microfoundations and adheres to non-structural arguments in representing persistence in inflation and output.

Our paper is also related to a lengthy literature that analyzes implications of inflation inertia

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[5]Some research from the late 1990s has disregarded the forward-looking term in the Philips curve and focused on entirely backward-looking specification of the curve (see for example Svensson (1997) and Rudebusch and Svensson (1999)). However this research is not set in a micro-founded framework.

[6]See the analysis and discussion related to the New Keynesian model in Clarida et al. (1999), who also provide references to the extensive literature related to this model.

[7]See Fuhrer and Moore (1995), Galí and Gertler (1999), Benigno and Lopez-Salido (2002), Mehra (2004)

for a design of monetary policy[8]. Within this strand of the literature there is a large body of research that investigates the implications of inflation persistence in the context of a monetary union. Benigno and Lopez-Salido (2002) analyze different inflation targeting policies under the presence of heterogeneity in inflation dynamics across euro area countries. By using, a micro-founded New Keynesian framework, they evaluate the welfare implications of different inflation targeting policies. A vital complement to work by Benigno and Lopez-Salido (2002) of investigation of optimal policies is an analysis of the stability of models under particular policy regimes, which have been thoroughly examined in a monetary union by Kirsanova et al. (2006). They show how members of the monetary union can be vulnerable to cyclical instability and show how the active use of fiscal policy can be used to mitigate or avoid this problem. Kirsanova et al. (2006a) also demonstrate that a higher proportion of forward-looking price setters moderate destabilizing effects following asymmetric shocks in the monetary union. These results agree with Westaway (2003) and Allsopp and Vines (2006), who also point out that a destabilizing tendency in the monetary union following shocks can be aggravated by more significant backward-looking element in inflation behavior. Analogous to their work, our paper aims to analyze dynamic adjustment in the face of external shocks in a small open economy, where backward-looking behavior is introduced. Inflation in the country is governed by a Phillips curve, that may be either backward-looking (accelerationist) or forward-looking (New Keynesian). We deliberately focus on these two limiting specifications of the Phillips curve to examine how backward-looking behavior changes the propagation of the shocks to the economy compared with a forward-looking specification, which has been extensively studied in the literature. We perform our analysis under two exchange rate regimes, a fixed rate and a flexible exchange rate, which allows us to discuss whether a small open economy will benefit from a flexible exchange rate in the presence of a substantial fraction of backward-looking price setters.

The reminder of the paper is structured as follows. Section 2 describes the model and defines a competitive equilibrium for the economy. Section 3 discusses calibration of the model. We discuss the simulation results in section 4. Section 5 concludes.

2   Model of a Small Open Economy

We consider a two sector dynamic stochastic general equilibrium model with nominal rigidities. The domestic economy is open and small and comprises three sectors: traded, non-traded goods, and the oil sector. We assume that oil production requires no domestic factor inputs, and all of its production is exported. The exogenous price of oil is subject to stochastic shocks. Our model assumes flexible price traded goods, traded in competitive markets, and a continuum of monopolistically produced non-traded goods. We assume Calvo-type price stickiness in the non-traded sector. While most of the papers that use the small open economy framework embody nominal inertia in terms of the form of Calvo contracts, we also allow for some additional inflation inertia, using a rule-of-thumb price setting mechanism outlined in Steinsson (2003). Domestic households consume both non-traded and traded goods. Traded goods could also be

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[8]A general overview of results for optimal policy in the presence of backward-looking settings is provided in Levin and Moessner (2005).

invested and imported from the rest of the world. Non-traded goods are also used to meet capital installation costs, which are a composite of both non-traded and traded goods in the same mix as the household's consumption basket. Households own production firms, supply labor and accumulate capital that they rent to production firms. As the owners of the firms producing non-traded goods, households also receive the income corresponding to the monopolistic rents generated by these firms. Non-traded goods firms produce differentiated varieties of non-traded goods. We consider two alternative monetary policy regimes: flexible and fixed exchange rate regimes. In both cases the monetary authority uses the nominal interest rate as a policy instrument and monetary policy is modeled through an interest rate rule.

2.1 Consumers

Consider a small open economy with non-traded goods, traded goods and oil. The economy is inhabited by a continuum of households with mass 1. The representative consumer has preferences given by:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t u(C_t, H_t) \tag{2.1}$$

where C_t is a composite consumption index and H_t is the labor supply. We assume the following functional form of utility function u:

$$u = \frac{C_t^{1-\sigma}}{1-\sigma} - \eta \frac{H^{1+\psi}}{1+\psi}$$

Composite consumption is a constant-elasticity-of-substitution (CES) function of traded goods and non-traded goods, with

$$C_t = [a^{\frac{1}{\rho}} C_{N,t}^{(\rho-1)/\rho} + (1-a)^{\frac{1}{\rho}} C_{T,t}^{(\rho-1)/\rho}]^{\rho/(1-\rho)}, \ \rho > 0,. \tag{2.2}$$

with $C_{N,t}$ and $C_{T,t}$ being indexes of consumption of non-traded and traded goods respectively. Under such specification of the composite consumption function, the parameter σ measures the (inverse) intertemporal elasticity of substitution and the parameter ρ is the intratemporal elasticity of substitution between non-traded and traded goods. The implied consumer price index is then

$$P_t = [a P_{N,t}^{1-\rho} + (1-a) P_{T,t}^{1-\rho}]^{\frac{1}{1-\rho}}$$

where $P_{N,t}$ is the price index of the composite differentiated non-traded good, $P_{T,t}$ is the price of flexible-price traded good, expressed in national currency, and P_t is the consumer price index.[9] Indexes of consumption of non-traded goods, in turn, is given by CES aggregators of the quantities consumed of each variety, with elasticity of substitution across different categories equal to λ:

$$C_{Nt} = (\int_0^1 C_{N,t}(j)^{\frac{\lambda-1}{\lambda}} dj)^{\frac{\lambda}{\lambda-1}}, \text{ with } \lambda > 1 \tag{2.3}$$

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[9] The price index P_t is the minimum expenditure required to purchase one unit of aggregate consumption good C_t. For the derivation see, for example, Obstfeld and Rogoff (2002).

where $C_{N,t}(j)$ is consumption of variety j by the representative household. When λ tends to infinity all varieties are perfect substitutes for each other. The price of variety j is denoted $P_{N,t}(j)$, and the price of a consumption basket of non-traded goods $P_{N,t}$ is defined as a CES index[10] with elasticity $1/\lambda$:

$$P_{N,t} = (\int_0^1 P_{N,t}(j)^{1-\lambda}dj)^{1/(1-\lambda)} \tag{2.4}$$

The optimal allocation of any given expenditure on non-traded goods yields the total demand for variety $j \in [0,1]$:

$$C_{N,t}(j) = (\frac{P_{N,t}(j)}{P_{N,t}})^{-\lambda}C_{N,t};$$

Households may borrow and lend in the form of non state-contingent bonds that are denominated in units of the traded goods. We assume that the borrowing rate i_t^F, charged on foreign debt depends on an exogenous world interest rate, i^*, and exogenous term ξ_t that capture external shocks to the borrowing rate:

$$(1 + i_t^F) = (1 + i^*)(1 + \xi_t) \tag{2.5}$$

The exogenous part of the foreign rate ξ_t follows a partial adjustment process:

$$\log(\xi_t) = (1 - \rho_\xi)\log\overline{\xi} + \rho_\xi\log(\xi_{t-1}) + \varepsilon_t^\xi, E(\varepsilon_t^\xi) = 0, var(\varepsilon_t^\xi) = \sigma_\xi^2 \tag{2.6}$$

Observe that in this paper we do not endogenize the interest rate, and do not use other methods (finitely-lived households, transactions costs in foreign assets, endogenous discount factor[11]) to rule out the nonstationary behavior of consumption and the current account. The nonstationary behavior of variables implies that unconditional variances do not exist, which poses problems for business cycle analysis. However, we are not interested in such analysis. In addition, the non-endogenized specification of foreign interest rate allows us to compare our results with the real business cycle (RBC) analogue of the model of this paper, discussed in Kuralbayeva and Vines (2006), which also assumes an interest rate specification similar to (2.5). Households can also obtain loans from domestic capital markets, with B_t the stock of domestic currency debt.

Households own firms that produce two goods: traded and non-traded goods in the economy. Households accumulate capital and rent it out to the goods producing firms. Capital stocks in non-traded and traded sectors are assumed to evolve according to the following:

$$K_{N,t+1} = I_{N,t} + (1 - \delta)K_{N,t}, \tag{2.7}$$

$$K_{T,t+1} = I_{T,t} + (1 - \delta)K_{T,t}, \tag{2.8}$$

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[10]This price index is the minimum expenditure required to buy one unit of aggregate consumption non-traded good $C_{N,t}$. For the derivation see, for example, Corsetti and Pesenti (2005).

[11]for further discussions of these methods see Schmitt-Grohé and Uribe (2001), Arellano and Mendoza (2002)

where investment in both sectors is traded good. Installation of capital in both sectors requires adjustment costs, which represent a basket of goods composed of non-traded goods and traded goods in the same mix as the household's consumption basket. We define capital adjustment costs as:

$$\phi_{i,t}(\frac{I_{i,t}}{K_{i,t}})K_{i,t} = \frac{\psi_I}{2}(\frac{I_{i,t}}{K_{i,t}} - \delta)^2 K_{i,t}, \text{ where } i = N, T,$$

so $\phi' > 0$, and $\phi'' > 0$.

The household's budget constraint in nominal terms is:

$$P_t C_t + P_t(\phi_{Nt} K_{Nt} + \phi_{Tt} K_{Tt}) + P_{Tt}(I_{Nt} + I_{Tt}) = W_t H_t + S_t D_{t+1} - (1 + i_t^F)S_t D_t + B_{t+1} - (1 + i_t)B_t +$$

$$R_{Nt} K_{Nt} + R_{Tt} K_{Tt} + P_{Tt} O_t + \int_0^1 \Pi_{Nt}(j)dj$$

(2.9)

where W_t is the wage rate; R_{Nt} and R_{Tt} are the nominal rates of return for households in the non-traded and traded sectors respectively; D_t is the outstanding amount of foreign debt, denominated in foreign currency, B_t is the stock of domestic debt, denominated in domestic currency, and S_t is the nominal exchange rate expressed as units of domestic currency needed for one unit of foreign currency. The household owns $K_{N,t}$ and $K_{T,t}$ units of capital in the non-traded and traded sectors, makes additional investments in both sectors of $I_{N,t}$ and $I_{T,t}$, consumes C_t and supplies H_t units of labor, and receives profits from the firms producing the non-traded goods, $\int_0^1 \Pi_{Nt}(j)dj$.

The household optimum is characterized by the following equations:

$$W_t = \eta H_t^\psi P_t C_t^\sigma \tag{2.10}$$

$$1 = \beta E_t[\frac{C_t^\sigma P_t}{C_{t+1}^\sigma P_{t+1}}(1 + i_{t+1})] \tag{2.11}$$

$$1 = \beta E_t[\frac{C_t^\sigma P_t}{C_{t+1}^\sigma P_{t+1}}\frac{S_{t+1}}{S_t}(1 + i_{t+1}^F)] \tag{2.12}$$

$$q_t^N = \beta E_t \frac{C_t^\sigma P_t}{C_{t+1}^\sigma P_{t+1}}\{R_{Nt+1} + P_{t+1}(\phi'_{N,t+1}\frac{I_{Nt+1}}{K_{Nt+1}} - \phi_{N,t+1}) + q_{t+1}^N(1 - \delta)\} \tag{2.13}$$

$$q_t^N = P_{Tt} + P_t \phi'_{N,t} \tag{2.14}$$

$$q_t^T = \beta E_t \frac{C_t^\sigma P_t}{C_{t+1}^\sigma P_{t+1}}\{R_{T,t+1} + P_{t+1}(\phi'_{T,t+1}\frac{I_{T,t+1}}{K_{T,t+1}} - \phi_{T,t+1}) + q_{t+1}^T(1 - \delta)\} \tag{2.15}$$

$$q_t^T = P_{Tt} + P_t \phi'_{T,t} \tag{2.16}$$

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along with the capital accumulation, (2.7)-(2.8), and budget constraint, (2.9), equations.

Equation (2.10) equates the marginal disutility of the labor effort to the utility value of the wage rate, and defines the households labor supply curve. Equation (2.11) is a Euler equation that determines intertemporal allocation: it equates the intertemporal marginal rate of substitution in consumption to the real rate of return on domestic bonds. Equation (2.13) is the counterpart of equation (2.12) for foreign bonds. Equation (2.13) is the pricing condition for physical capital in the non-traded sector. It equates the revenue from selling one unit of capital today (q_t^N), to the discounted value of renting the unit of capital for one period, and then selling it, $R_{N,t+1} + q_{t+1}^N$, net of depreciation and adjustment costs[12]. Equation (2.14) relates the cost of producing a unit of capital in the non-traded sector to the shadow price of installed capital, or Tobin's Q, q_t^N. Equations (2.15), and (2.16) are the traded sector counterparts of (2.13) and (2.14). Equation (2.11) in conjunction with (2.12) yields the uncovered interest parity condition (UIP):

$$E_t\{C_{t+1}^{-\sigma}\frac{P_t}{P_{t+1}}[(1+i_{t+1}) - (1+i_{t+1}^F)\frac{S_{t+1}}{S_t}]\} = 0 \tag{2.17}$$

Given a decision on consumption C_t the household allocates optimally the expenditure on $C_{N,t}$ and $C_{T,t}$ by minimizing the total expenditure $P_t C_t$ under the constraint (2.2), so demands for non-traded and traded goods are:

$$C_{Nt} = a(\frac{P_{N,t}}{P_t})^{-\rho}C_t \tag{2.18}$$

$$C_{Tt} = (1-a)(\frac{P_{M,t}}{P_t})^{-\rho}C_t \tag{2.19}$$

2.2   Production by Firms

We assume a continuum of monopolistically competitive firms of measure unity in the non-traded sector, each producing output with the production function:

$$Y_{N,t}(j) = A_N K_{N,t}(j)^\alpha H_{N,t}(j)^{1-\alpha} \tag{2.20}$$

where A_N is a productivity parameter, which is the same across the firms in the non-traded sector. Firms in the traded sector operate under perfect competition with the production function given by:

$$Y_{T,t}(j) = A_T K_{T,t}(j)^\gamma H_{T,t}(j)^{1-\gamma} \tag{2.21}$$

where A_T is a productivity parameter, and is also the same across the firms in the traded sector. There are also a mass of one of firms producing traded goods. We assume all firms rent capital and labor in perfectly competitive factor markets. Cost minimization implies equations:

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[12]Adjustments are costs stemming from decreasing the capital stock. The installation function $\phi_{Nt}K_{Nt}$ as a function of I_{Nt} shifts upwards as K_{Nt} decreases, which is represented by $\partial/\partial K_{Nt+1}(\phi_{Nt+1}K_{Nt+1}) = -\phi'_{Nt+1}I_{N,t+1}/K_{Nt+1} + \phi_{Nt+1}$ in (2.13).

$$W_t = MC_{N,t}(1-\alpha)\frac{Y_{N,t}}{H_{N,t}} \tag{2.22}$$

$$R_{N,t} = MC_{N,t}\alpha\frac{Y_{N,t}}{K_{N,t}} \tag{2.23}$$

$$W_t = P_{T,t}(1-\gamma)\frac{Y_{T,t}}{H_{T,t}} \tag{2.24}$$

$$R_{T,t} = P_{T,t}\gamma\frac{Y_{T,t}}{K_{T,t}} \tag{2.25}$$

where $Y_{N,t} = A_N K_{N,t}{}^\alpha H_{N,t}{}^{1-\alpha}$ and $Y_{T,t} = A_T K_{T,t}{}^\gamma H_{T,t}{}^{1-\gamma}$ are aggregate supply functions of non-traded and traded goods[13]. Demand for labor and capital in the non-traded goods sector is described by equations (2.22)-(2.23), where $MC_{N,t}$ represents the (nominal) marginal costs in that sector. It is noteworthy that the marginal costs in the non-traded sector are identical across firms as long as their production functions exhibit constant returns to scale and prices of inputs are fully flexible in perfectly competitive markets. Producers of the traded goods are price-takers, so that equations (2.24)-(2.25) describe the demand for labor and capital inputs in the traded sector, with $P_{T,t}$ representing the unit cost of production.

2.3 Price setting in the non-traded sector

In order to describe the price setting decisions we split firms into two groups according to their pricing behavior, following Steinsson (2003). In each period, each firm changes its price with probability $1 - \theta_N$, and otherwise, with probability θ_N, its price will rise at the steady state rate of inflation $\Pi_{N,t} = P_{N,t}/P_{N,t-1}$. Among those firms which reset their price, a proportion of $1 - \omega$ are forward-looking and set prices optimally, while a fraction ω are backward-looking and set their prices according to a rule of thumb.

Forward-looking firms are profit-maximizing and reset prices $(P_{N,t}^F)$ optimally, which in terms of log-deviations from the steady state (see Technical appendix) implies:

$$\widehat{p}_{N,t}^F = \widehat{mc}_{N,t} + E_t\sum_{i=1}^{\infty}(\theta_N\beta)^i[\widehat{mc}_{N,t+i} - \widehat{mc}_{N,t+i-1}] + E_t\sum_{i=1}^{\infty}(\theta_N\beta)^i\pi_{N,t+i} \tag{2.26}$$

where $\pi_{N,t}$ is inflation in the non-traded sector and $\widehat{mc}_{N,t}$ stands for the deviation of real marginal costs from its steady state. As discussed in Christiano et al. (2001), relation (2.26) shows several important features of the behavior of the forward-looking firms. When firms expect real marginal costs to be higher in the future and/or expect future increases in the price level, then the firms set $\widehat{p}_{N,t}^F$ higher than $\widehat{mc}_{N,t}$. Christiano et al. (2001) describe this behavior as '*front loading*'. Firms understand that they might not be allowed to change their price when higher real marginal costs or higher prices materialize. So, anticipating this, forward-looking firms set prices to maximize their current and future profits, taking into account the future

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[13]With respect to aggregation in the non-traded sector, in the appendix we show that the non-traded market equilibrium equation has an additional term that deals with the distribution of prices in the non-traded sector. However, as shown in the appendix (see also Yun (1996), Erceg et. al. (2000) and Christiano et. al. (2001)), this term does not appear in the log-linear approximation of the resource constraint in the non-traded sector.

evolution of real marginal costs and prices. Further, for derivation of the Phillips curve below, it is convenient to re-write relation (2.26) as:

$$\widehat{p}^F_{N,t} = (1 - \beta\theta_N)\widehat{mc}_{N,t} + \beta\theta_N\widehat{p}^F_{N,t+1} + \beta\theta_N\pi_{N,t+1} \tag{2.27}$$

Backward-looking firms set their prices according to the following rule[14]:

$$P^B_{N,t} = P^r_{N,t-1}\Pi_{N,t-1}(\frac{Y_{N,t-1}}{Y^n_{N,t-1}})^\vartheta \tag{2.28}$$

where $\Pi_{N,t-1} = P_{N,t-1}/P_{N,t-2}$ is the past period growth rate of prices in the non-traded sector, $Y_{N,t-1}/Y^n_{N,t-1}$ is output relative to the flexible-price equilibrium, $P^r_{N,t-1}$ is an index of prices set at date $t-1$, given in terms of log-deviations from the steady state (see Appendix) by:

$$\widehat{p}^r_{N,t-1} = (1 - \omega)\widehat{p}^F_{N,t-1} + \omega\widehat{p}^N_{N,t-1} \tag{2.29}$$

The rule of thumb (2.28) shows that backward-looking firms set their prices equal to the average of the newly set prices in the previous period updated by the previous period inflation rate of the non-traded goods price level and by the deviation of the non-traded goods output relative to the flexible price equilibrium non-traded output. This assumption, as discussed in Galí and Gertler (1999) has the following appealing properties: first, the rule of thumb behavior converges to the optimal behavior over time; and second, $P^B_{N,t}$ depends only on information up to the period $t-1$, but implicitly incorporates past expectations about the future, since the price index $P^r_{N,t-1}$ is partly determined by forward-looking price setters.

For the whole non-traded sector, the price index in the non-traded sector is given by:

$$P_{N,t} = [(1 - \theta_N)(1 - \omega)(P^F_{N,t})^{1-\lambda} + (1 - \theta_N)\omega(P^B_{N,t})^{1-\lambda} + \theta_N(\Pi_N P_{N,t-1})^{1-\lambda}]^{\frac{1}{1-\lambda}} \tag{2.30}$$

Following Steinsson (2003), we can derive the following Phillips curve for the non-traded sector, written in terms of log-deviations from the steady state[15]:

$$\pi_{N,t} = \chi^f\beta E_t\pi_{N,t+1} + \chi^b\pi_{N,t-1} + \kappa_1\widehat{y}_{N,t-1} + \kappa_2\widehat{y}_{N,t} + \kappa_{mc}\widehat{mc}_{N,t} \tag{2.31}$$

where the coefficients are:

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[14] There is no consensus on a way of introducing inflation persistence. In the micro-founded way there are two main mechanisms. First is a rule-of-thumb price-setting behaviour that we follow in this paper (see also Kirsanova et. al. (2006)). The second mechanism is a backward-looking price indexation (Christiano et. al. (2001), Smets and Wouters (2002), Woodford (2003)). Each period only a fraction of firms re-optimize their prices, while the remaining firms index their prices to a fraction of the lagged inflation rate. As an alternative to micro-founded mechanisms above, inflation intertia can be modeled on the basis of adaptive expectations as in Roberts (1997), on the basis of sticky information as in Mankiw and Reis (2001), or as a signal extraction problem in Erceg and Levin (2001).

[15] The derivation is identical to one in Steinsson (2003) and Kirsanova et. al. (2006), amended by the introduction of the real marginal costs and by accounting for the non-traded sector. A detailed derivation is given in the technical appendix.

$$\chi^f = \frac{\theta_N}{\theta_N + \omega(1 + \theta_N\beta - \theta_N)}, \quad \chi^b = \frac{\omega}{\theta_N + \omega(1 + \theta_N\beta - \theta_N)},$$

$$\kappa_1 = \frac{\omega\vartheta(1 - \theta_N)}{\theta_N + \omega(1 + \theta_N\beta - \theta_N)}, \quad \kappa_2 = -\frac{\beta\theta_N\omega\vartheta(1 - \theta_N)}{\theta_N + \omega(1 + \theta_N\beta - \theta_N)},$$

$$\kappa_{mc} = \frac{(1 - \beta\theta_N)(1 - \omega)(1 - \theta_N)}{\theta_N + \omega(1 + \theta_N\beta - \theta_N)}.$$

and where $\widehat{y}_{N,t}$ is the output gap in the non-traded sector, defined as the deviation from the flexible price output of the non-traded sector $(Y^n_{N,t})$, and $mc_{N,t}$ are real marginal costs in the non-traded sector.

All coefficients are explicit functions of three model parameters: θ_N which measures the degree of price stickiness in the non-traded sector; ω which measures the degree of 'backwardness' in price setting, and the discount factor β. Coefficients on the output gaps, κ_1 and κ_2, also depend on the elasticity ϑ. In this model, the degree of inflation inertia can be measured by the fraction of backward-looking firms, as a larger fraction of backward-looking firms implies a higher value of the coefficient of the lagged inflation, χ^b. As one would anticipate, a rise in ω leads to a fall in the coefficients of current variables, κ_2 and κ_{mc}, and to a rise in the coefficient of the predetermined variable, κ_1. Moreover, a higher degree of backwardness in the model implies a lower weight on the currently expected future inflation, χ^f. This is because only forward-looking firms react immediately to changes in current market conditions.

Note that when $\omega = 0$ the Phillips curve collapses to the standard forward-looking specification:

$$\pi_{N,t} = \frac{(1 - \beta\theta_N)(1 - \theta_N)}{\theta_N}\widehat{mc}_{N,t} + \beta E_t\pi_{N,t+1} = \lambda_N\widehat{mc}_{N,t} + \beta E_t\pi_{N,t+1} \qquad (2.32)$$

When $\omega = 1$ the Phillips curve takes the specification:

$$\pi_{N,t} = \frac{\theta_N\beta}{1 + \theta_N\beta}E_t\pi_{N,t+1} + \frac{1}{1 + \theta_N\beta}\pi_{N,t-1} - \frac{1 - \theta_N}{1 + \theta_N\beta}[\beta\theta_N\vartheta\widehat{y}_{N,t} - \vartheta\widehat{y}_{N,t-1}] \qquad (2.33)$$

As noted in Steinsson (2003), (2.33) has a unique bounded solution:

$$\pi_t = \pi_{t-1} + (1 - \theta_N)\vartheta\widehat{y}_{N,t-1} \qquad (2.34)$$

which is a form of the accelerationist Phillips curve and has no forward-looking component.

2.4 Local Currency Pricing

We assume that the price of the traded good is flexible and determined by the law of one price, so:

$$P_{T,t} = S_t P^*_{T,t}$$

where $P^*_{T,t}$ is the foreign currency price of the traded good, and S_t is the nominal exchange rate. The economy is small also in the respect that the economy's export share is negligible in the foreign aggregate price index, implying that the foreign price of traded goods is equal to the foreign aggregate price level, and we assume that it is equal to unity, so $P^*_{T,t} = P^*_t = 1$, and $P_{T,t} = S_t$.

Defining the real exchange rate as, $e_t = S_t P_t^* / P_t$, so the real exchange rate depreciates (appreciates) when e_t rises (decreases). The rate of change of the real exchange rate is given as:

$$\frac{e_t}{e_{t-1}} = \frac{1 + \nu_t}{1 + \pi_t} \tag{2.35}$$

and the nominal exchange rate depreciation in period t is given by:

$$1 + \nu_t = \frac{S_t}{S_{t-1}} \tag{2.36}$$

2.5   Monetary policy

We assume that the monetary authority uses the nominal interest rate as the policy instrument. We consider two alternative monetary policy regimes: flexible and fixed exchange rate regimes. In the first, the flexible exchange rate regime monetary policy is characterized as a Taylor rule:

$$\log(\frac{1 + i_t}{1 + i}) = \rho_Y \log(\frac{Y_{Nt}}{Y_{N,t}^n}) + \rho_\pi \log(\frac{1 + \pi_{N,t}}{1 + \overline{\pi}_N}) \tag{2.37}$$

where $\overline{\pi}_N$ is the target for the annual inflation in the non-traded sector, i is the stationary value of the interest rate, and $Y_{N,t}/Y_{N,t}^n$ is output of the non-traded sector relative to its flexible-price equilibrium. Log-linearization of the feedback rule yields:

$$\widehat{i}_t = \rho_Y \widehat{y}_{N,t} + \rho_\pi \pi_t \tag{2.38}$$

where $\rho_Y > 1$, and $\rho_\pi > 0$ are the reaction coefficients on non-traded goods inflation and $\widehat{y}_{N,t}$ is the output gap in the non-traded sector.

Alternatively, monetary policy is characterized by the following interest rate rule that delivers a fixed exchange rate:

$$1 + i_t = (1 + i_t^F)(\frac{S_t}{\overline{S}})^{\omega_S} \tag{2.39}$$

where $\omega_S > 0$, and $S_t = \overline{S} \; \forall t$. Under this rule, the monetary authority pegs the nominal exchange rate at a target level $\overline{S}$ in all periods by varying the nominal interest rate in reaction to movements in the foreign interest rate and deviations of the nominal exchange rate from the target[16].

2.6   Equilibrium

The equilibrium of the economy is a sequence of prices $\{P_t\} = \{W_t, i_t^F, i_t, P_{N,t}, S_t, R_{N,t}, R_{T,t}\}$ and quantities $\{\Theta_t\} = \{\{\Theta_t^h\}, \{\Theta_t^f\}\}$ with

$\{\Theta_t^h\} = \{H_t, C_t, C_{Nt}, C_{Tt}, D_t, B_t, K_{N,t+1}, K_{T,t+1}, I_{Nt}, I_{Tt}\}$

$\{\Theta_t^f\} = \{H_{Nt}, H_{Tt}, K_{Nt}, K_{Tt}, Y_{Nt}, Y_{Tt}, X_{Tt}\}$,

such that:

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[16] Benigno et. al. (2005) show that such kind interest rate rule ensures determinacy of the exchange rate and the real economy. Such rules produce equality between the domestic and foreign interest rate endogenously in all periods as a feature of the rational expectations equilibrium.

(1) given a sequence of prices $\{P_t\}$ and a sequence of shocks, $\{\Theta_t^h\}$ is a solution to the representative household's problem;

(2) given a sequence of prices $\{P_t\}$ and a sequence of shocks, $\{\Theta_t^f\}$ is a solution to the representative firms in non-traded and traded sectors;

(3) given a sequence of quantities $\{\Theta_t\}$ and a sequence of shocks, $\{P_t\}$ clears the markets:

(i) Labor market:

$$H_{Xt} + H_{Nt} = H_t \tag{2.40}$$

(ii) Capital market:

$$K_{N,t}^S = K_{N,t}^D \quad K_{X,t}^S = K_{X,t}^D \tag{2.41}$$

(iii) Non-traded goods sector:

$$\int_0^1 Y_{Nt}^S(j)di = \Delta_t Y_{Nt}^D \tag{2.42}$$

where Δ_t is a measure of relative price dispersion in the non-traded goods sector[17] and Y_{Nt}^D is the aggregate demand of non-traded goods in the economy, defined as:

$$Y_{Nt}^D \equiv a(\frac{P_{Nt}}{P_t})^{-\rho}[C_t + \phi_{N,t}K_{Nt} + \phi_{T,t}K_{Tt}] \tag{2.43}$$

(iv) Traded goods sector:

$$A_{Tt} = Y_{Tt} + IM_{Tt} \tag{2.44}$$

where domestic absorption of traded goods A_{Tt} is met via domestic production of traded goods Y_{Tt} and imports IM_{Tt}:

$$A_{Tt} \equiv (1-a)(\frac{P_{Tt}}{P_t})^{-\rho}[C_t + \phi_{N,t}K_{Nt} + \phi_{T,t}K_{Tt}] + I_{Nt} + I_{Tt} \tag{2.45}$$

(v) Foreign loans market:

$$D_t^S = D_t^D \tag{2.46}$$

(vi) Domestic loans market:

$$B_t = 0 \tag{2.47}$$

(vii) Balance of Payments:

$$A_{Tt} + (1 + i_t^F)D_t = D_{t+1} + Y_{Tt} + O_t \tag{2.48}$$

(4) Prices are set to satisfy (2.17), (2.37) (or(2.39)), (2.40), (2.41), (2.42), (2.46).

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[17] See technical appendix for more details on this.

3 Calibration

In calibrating the model one period is meant to be one quarter. The parameter choices of the model are described in Table 1, while Table 3 reports macroeconomic ratios implied by the theoretical model. We set the following parameters of the utility function: σ, the inverse intertemporal elasticity of substitution in consumption, equal to unity[18]; the value of coefficient on labor $\eta = 1$, and $\psi = 0.45$[19], so that elasticity of the labor supply is 2.22. The elasticity of substitution between non-traded and traded goods (ρ) is set to 1.2.[20]

We set the value of a, the share of non-traded goods in CPI, equal to 0.65, which implies the steady state share of non-traded goods in GDP is 45 percent. We set the depreciation rate at 10 percent per annum, a standard value in the business cycle literature. The value of the adjustment cost parameter, ψ_I is set at 0.1. This is consistent with empirical estimates of the adjustment cost parameter in the literature, although these estimates are for developed countries[21].

We set the steady-state real interest rate faced by the small economy in international markets at 11 percent per annum, with a world interest rate r^* of 4 percent and a country premium of 7 percent. These parameters yield a value of the subjective discount factor, β, of 0.973. The steady state value of oil income, O, was chosen such that oil transfers constitute 25 percent of GDP. We also set the steady state value of foreign borrowing equal to 60 percent of GDP. The elasticity of substitution between differentiated goods is set to equal 11, which implies a steady state mark-up of 10%. This is within the range suggested by the literature.[22]

Table 1 Calibration of the model

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[18] Ostry and Reinhart (1992) provides an estimate of σ for a group of Asian countries at 0.8. Aurelio (2005) uses the value of $\sigma = 1$ in her simulations. Gali and Monacelli (2002) assume log-utility of consumption, which also implies a unit intertemporal elasticity of substitution.

[19] Uribe and Yue (2005) also set $\psi = 0.45$

[20] Ostry and Reinhart's estimates of the parameter for Asian and Latin American countries equal 0.655 and 0.76 respectively, using one set of instruments, and 1.15 and 1.1 for a different set of instruments respectively. Mendoza (2001) sets $\rho = 1.46$.

[21] Hall (2002) estimates a quadratic adjustment cost for capital and finds a slightly higher value of 0.91 for ψ_I, on average, across industries. A much closer value of 0.096 is found recently by Groth (2005) for estimates of capital adjustment costs for UK manufacturing covering the period 1970-2000.

[22] Gali (2003) sets $\lambda = 11$ as well, while in Gali and Monacelli (2002) the value of this parameter is equal to 6. The empirically plausible range of 10% - 40% for markups, as Gali et. al. (2001) discuss, yields similar results.

Parameter	Value	Description
σ	1	Inverse of elasticity of substitution in consumption
β	0.973	Discount factor
ρ	1.2	Elasticity of substitution between non-traded and traded goods in C_t
η	1	Coefficient on labor in utility
ψ	0.45	Inverse of elasticity of labor supply ($1/\psi = 2.22$)
γ	0.65	Share of capital in traded sector
α	0.25	Share of capital in non-traded sector
δ	0.025	Quarterly rate of capital depreciation (same across sectors)
a	0.65	Share on non-traded goods in CPI
ψ_I	0.1	Investment adjustment cost (same across sectors)
θ_N	0.75	Probability of fixed price
ϑ	0.36	Elasticity of deviation of the output gap in the rule-of-thumb
λ	11	Elasticity of substitution between differentiated goods
ω	0.01 and 0.9	Proportion of backward-looking firms
ρ_Y	0.5	coefficient on output gap in Taylor rule
ρ_π	1.5	coefficient on inflation in Taylor rule

In our simulations, perhaps the most important variable is ω, the proportion of rule-of-thumb price setters. As $0 \leqslant \omega \leqslant 1$, our model nests the purely forward-looking new Keynesian model ($\omega = 0$), the purely backward-looking acceleration model ($\omega = 1$), as well as other models such as in Fuhrer and Moore (1995) ($0 < \omega < 1$). Empirical studies conclude that an empirical Phillips curve has a statistically significant backward-looking component. The estimates of coefficients on 'backwardness' and 'forwardness', however, vary widely among studies. Backward-looking behavior is of limited quantitative importance in the estimated specifications of Galí and Gertler (1999) and Benigno and Lopez-Salido (2006). Mehra (2004) finds an extremely backward-looking specification of the Phillips curve, while Fuhrer and Moore (1995) claim that an equal weight on forward and backward inflation terms matches the pattern of US data much better than either a purely backward-looking or purely forward-looking model.

Galí and Gertler (1999) estimate a Phillips curve by using non-linear instrumental variables (GMM), using a measure of marginal costs instead of a measure of the output gap, which is a close relative of the Phillips curve derived in this model. They report estimates of θ_N between 0.803 and 0.866, β between 0.885 and 0.957, κ_{mc} between 0.015 and 0.037,[23] ω between 0.077 and 0.522 (with 3 out of their 6 estimates being between 0.2 and 0.3), χ^f between 0.62 and 0.92 (with 4 out of their 6 estimates being between 0.78 and 0.92), and χ^b between 0.085 and 0.383. In this paper, we are interested in analyzing how backward-looking behavior affects adjustment dynamics in response to the shocks compared with forward-looking behavior. That is why we consider two limiting cases. In the first case, inflation exhibits very little persistence and price setters are almost completely forward-looking, assuming $\omega = 0.01$. In the second case, inflation is almost completely persistent and we set $\omega = 0.9$. These values of ω, with the appropriate

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[23]Note that their estimate of κ_{mc} does not correspond exactly to κ_{mc}, coefficient before marginal costs in Phillips curve in our model, as our specification contains an additional term with the output gap.

choice of elasticity ϑ, imply the values of structural parameters of the Phillips curve, reported in Table 2.

To calibrate the parameter ϑ, we follow Steinsson's procedure, which is as follows. The value of ω varies between zero and one. So, when $\omega \to 0$, it collapses to the familiar forward-looking specification $\pi_{N,t} = \lambda_N \widehat{mc}_{N,t} + \beta E_t \pi_{N,t+1}$, whilst when $\omega \to 1$, it collapses to $\pi_t = \pi_{t-1} + (1 - \theta_N)\vartheta \widehat{y}_{N,t-1}$, which is an accelerationist Phillips curve. In calibrating ϑ, Steinsson assumes that demand pressure is the same across these two extreme cases, i.e. $\lambda_N = (1 - \theta_N)\vartheta$. Chosen in this way, $\vartheta = (1 - \beta\theta_N)/\theta_N = 0.36$.

Table 2 Values for the structural parameters of the Phillips curve for different values of ω

ω	χ^f	χ^b	κ_1	κ_2	κ_{mc}
0.01	0.98	0.013	0	0	0.087
0.9	0.46	0.55	0.05	-0.036	0.004

We follow the literature[24] in setting $\theta_N = 0.75$, which implies that, on average, prices last for one year.

In this paper we study a *permanent* improvement in the price of oil and a *permanent* reduction in the risk-premium. We do not examine the impact of productivity shocks and we set the values of the productivity parameters, A_N and A_X, in two sectors equal to unity. In the model, shocks to oil prices are represented by shocks to ε_t, and shocks to the risk premium are represented by shocks to ξ_t.

With the benchmark parameters summarized in the Table 1 the model generates an economy that has the following structure in the steady state:

Table 3 Structure of the theoretical economy

External debt/GDP	60%
Traded production/GDP	31%
Absorption of traded goods/GDP	54%
Non-traded production/GDP	44%
Oil/GDP	25%
Investment in non-traded sector/GDP	5%
Investment in traded sector/GDP	9%
Capital in non-traded sector/GDP	2.09
Capital in traded sector/GDP	3.83
Consumption/GDP	84%
Consumption of non-traded goods/GDP	44%
Consumption of traded goods/GDP	40%
Labor income/GDP	44%
Employment in non-traded sector/Total Employment	75%
Employment in traded sector/Total Employment	25%

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[24] The micro analysis on price stickiness gives mixed results. Golosov and Lucas (2003) suggest that firms change prices on average about 2 quarters. Baudry's et al. (2004) analysis suggests 3 quarters, while Aucremanne and Dhyne (2004) find a value of 5.

4 Simulations

In this section we present results of simulations of the model under exogenous shocks: oil price shock and risk-premium shocks. We study a permanent, 1 percentage improvement in the price of oil, and a permanent, 1 percentage reduction in the risk-premium. Before examining the results of simulations of the model to these shocks, we briefly discuss the flexible analogue of the open-economy model and its responses to the same shocks. That provides a useful benchmark for the analysis of impulse responses of the model with sticky prices in the subsequent sections.

4.1 Flexible price equilibrium

The model collapses to the flexible price equilibrium in the case when firms change their price with probability one, that is $\theta_N = 1$. We assume that in flexible price equilibrium there is no distinction between backward-looking and forward-looking firms, product markets are monopolistically competitive and firms set prices as a mark-up over marginal costs.

Monetary policy consistent with a flexible price equilibrium can be found by substituting the paths for inflation, $\pi_t = 0$, into the intertemporal relation (2.11). The interest rate instrument of the central bank must satisfy $i_t = r_t^n$ at all times, where:

$$1 + r_{t+1}^n \equiv \beta^{-1}\{E_t[\frac{C_t^\sigma}{C_{t+1}^\sigma}]\}^{-1} \tag{4.1}$$

r_t^n is the natural rate of interest, which is defined as the equilibrium real rate of return in the case of fully flexible prices.

Figures 1-2 illustrate impulse responses of the flexible price equilibrium model to the oil and risk-premium shocks. It is worth noting that the flexible-price dynamics of the present model are fully equivalent to those of a RBC version of the current model considered in Kuralbayeva and Vines (2006). The important difference between a RBC model and the flexible-price limit of the model considered here, as pointed out by Woodford (2003), is that product markets are competitive in the former, rather than monopolistically competitive in later case. In the RBC model, the marginal costs of production are the same for all firms at all times, because inputs of production are purchased on the same competitive rental market. While, in the flexible price limit of the sticky price model, prices charged by firms are the same, as well as the levels of production of each good, so that marginal costs are in fact the same for all firms.

4.2 Flexible exchange rate regime

In this section we report results from simulations of the sticky-price model under a flexible exchange rate regime[25].

4.2.1 Oil shock

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[25] In impulse responses functions p_n denotes relative price of the non-traded goods, while P_n is aggregate price index of the non-traded goods, so that $p_{n,t} = P_{n,t}/P_t$.

Figures 3-4 display impulse responses to the shock for the value $\omega = 0.01$, while figures 5-6 show the reaction of the variables to the shock in the case of $\omega = 0.9$.

A positive oil shock increases demand for both non-traded and traded goods. As in the non-traded sector prices are sticky and output is demand-determined, the firms that are not able to reset prices increase output as long as their prices are above marginal costs. This pushes demand for labor up. As no imperfections exist in the labor market, the nominal wage must increase. Due to the price stickiness, this generates an increase in the real wage. As real marginal costs increase on the impact of the shock, lucky firms (those able to reset their prices) find it profitable to set a price above the average price of the previous period. In setting their price, forward-looking firms, due to the 'front loading' behavior, also take into account the future expected changes in real marginal costs. So, the price set by lucky firms is above the average price that prevailed in the previous period, which causes an increase in the price of non-traded goods and inflation in that sector.

This is very different from what happens if inflation is almost entirely backward-looking. In that case the response of inflation is hump shaped. The reason for such different adjustment of inflation can be seen as follows. Because of the rule-of-thumb behavior, backward-looking firms do not react contemporaneously to unexpected shocks. As a result, inflation rises only slightly on the impact of the shock. But as real marginal costs rises in the non-traded sector and some (even very small) fraction of forward-looking firms set prices higher than in previous periods, inflation starts picking up in the non-traded sector in subsequent periods.

Under both cases the central bank accommodates the oil shock by increasing the (nominal) interest rate. The real interest rate also rises, given the Taylor principle. This monetary tightening helps to suppress demand, directly via the real interest rate effect and indirectly via its effect on the real exchange rate. Both of these effects curb inflation. There is a corresponding increase in the output gap, which causes additional monetary tightening and reinforces the interest rate effect.

The nominal exchange rate appreciates on the impact of the positive demand shock. Thereafter, the higher interest rate results in a nominal depreciation of the exchange rate via the uncovered interest parity condition (UIP). The long-run depreciation of the nominal exchange rate is offset by an increase in the CPI price index of the same magnitude, so that in the long-run the real exchange rate moves back to its initial level. Thus, with an independent monetary policy the nominal exchange rate facilitates adjustment to the shock, which is reflected in a smooth movement of the real exchange rate back to equilibrium level.

Two further points about the behavior of the real interest rate and inflation are worth noting. First, in case of $\omega = 0.9$, inflation slowly increases and then converges to its steady state at a very slow speed as well. It seems to peak about eight quarters after the shock. Second, despite very different dynamic responses of inflation and the (nominal) interest rate in the two cases, the real interest rate responses are very similar. This is because nominal interest rates closely follows the dynamics of inflation, and hence the real interest rate reaction in case of the accelerationist Phillips curve has the same pattern of behavior as in the case of the forward-looking Phillips curve. So, both real interest rates rise on the impact of the shock and then gradually converge to zero in the long-run. Given similar variations in the real interest rate, it is not surprising

that the reaction of real variables are very similar too. Moreover, those responses are much like that in the flexible price model. To see why it happens, consider the log-linearized version of the Euler equation (2.11):

$$\widehat{i}_{t+1} = \pi_{t+1} + \sigma(\widehat{C}_{t+1} - \widehat{C}_t) \tag{4.2}$$

Given the definition of the natural rate of interest, one observes that the log-linearized version of the Euler equation (4.2) can be re-written as:

$$\widehat{i}_{t+1} = \widehat{r}^n_{t+1} + \pi_{t+1} \tag{4.3}$$

The real interest rate that matters for the firms in the non-traded sector is defined as $\widehat{r}_{t+1} = \widehat{i}_{t+1} - \pi_{N,t+1}$. Using the identity for aggregate inflation, $\pi_{t+1} = \pi_{N,t+1} - (\widehat{p}_{N,t+1} - \widehat{p}_{N,t})$, the real interest rate faced by non-traded sector firms can be related to the natural rate of interest in the following way:

$$\widehat{r}_{t+1} = \widehat{r}^n_{t+1} - (\widehat{p}_{N,t+1} - \widehat{p}_{N,t}) \tag{4.4}$$

where $\widehat{p}_{N,t}$ is the log-linearized version of the relative price of the non-traded sector ($p_{N,t} = P_{N,t}/P_t$). As identity (4.4) reveals the only time when there is a considerable difference between the real interest rate and the natural rate of interest is at the time of the shock, while at all other times the difference $\Delta\widehat{p}_{N,t+1} \equiv (\widehat{p}_{N,t+1} - \widehat{p}_{N,t})$ remains very small. So, in this model variations in the monetary authority's instrument track variations in the natural rate of interest, so that the real interest rate faced by the non-traded sector firms is approximately equal to the natural rate of interest throughout the adjustment period to the shock. As discussed in Woodford (2003), such a Taylor rule policy, with characteristics above, would succeed in stabilizating inflation. As a result, the flexible price equilibrium is replicated here in the sense that real variables respond to the oil shock in a similar way to reactions of variables in the flexible-price model. In general, as noted by Woodford (2003), required variations in the natural rate of interest in response to the various types of shocks to replicate an equilibrium consistent with stable prices cannot be achieved through a simple Taylor rule. The assumption in our model, which is crucial in replicating the flexible price outcome, is flexibility of prices of traded goods. As shown in Smets and Wouters (2002), when prices of both sectors are sticky, there will be a trade-off between stabilizing prices of domestic goods and stabilizing imported price inflation. If one of these two sectors is flexible, it is optimal for the central bank to stabilize inflation in the sector with sticky prices, and the flexible price equilibrium is replicated. This result is consistent with earlier work by Aoki (2001), who also finds within two-sector model (a flexible price and sticky price sector, but without inflation inertia) that it is optimal to target inflation in the sticky-price sector, rather than to target aggregate inflation. When inflation is completely stabilized, the responses of the economy are equivalent to those of the flexible price model.

4.2.2 Risk-premium shock

Figures 7-8 present the impulse responses of the model to the shock for the value $\omega = 0.01$, while figures 9-10 illustrate the reaction of the variables to the shock for the value of $\omega = 0.9$.

A permanent reduction in the foreign interest rate reduces the marginal costs of capital. Lucky firms (who are able to reset their prices) find it profitable to set a price below the average price of the previous period, which causes disinflation on the impact of the shock. In the case of backward-looking firms, inflation rate does not react to changes in current real marginal costs, so inflation almost remains at its initial steady state level on impact of the shock.

After the initial response to the shock, inflation declines before increasing towards its new steady state level for both values of ω. This is because (real) marginal costs are falling in the periods following the shock and then are increasing towards the new long-run equilibrium level. To explain this dynamic adjustment of inflation, we should notice that the outcome of the short-run is an increase in the return on capital in both traded and non-traded sectors, with a bigger increase on capital profitability in the non-traded sector.[26] This rise of return on capital in the non-traded sector will cause capital inflow into the sector.

During some period following the shock the non-traded sector modifies the optimal mix of factors of production in favor of more capital and less labor, so production costs fall. Given the reduction in (real) marginal costs, the price of non-traded goods is falling during that period. However, as the wage rate has been rising throughout the adjustment period, pressures that were making inflation fall will weaken. So, there will come a time when inflation starts rising again (although remaining negative) towards its new long-run equilibrium level. This process is slower in the case of the accelerationist Phillips curve compared to the forward-looking Phillips curve, given the rule-of-thumb behavior of backward-looking firms.

Note that in the long-run inflation does not converge to its initial steady state level, which is different from the behavior of inflation in the long-run in response to an oil shock. The reason is that we now consider a permanent risk-premium shock, which changes marginal costs of production.

As inflation is negative throughout the adjustment period as well as in a new equilibrium, prices are falling permanently. Thus the real exchange rate appreciation occurs via appreciation of the nominal exchange rate, which offset the decline in the price level. Correspondingly, the burden of real exchange rate adjustment is taken by nominal exchange rate with smaller increase in prices. A permanent, 1 percentage reduction in the risk-premium assumes near 1 percent permanent decrease in the foreign interest rate on external borrowings by the country. In the long-run interest rate falls by 4.2 percentage points in case of $\omega = 0.01$ and by 4.5 percentage points in case of $\omega = 0.9$, the nominal exchange rate appreciates via the UIP condition with a constant rate of appreciation of 3.2 percent and 3.5 percent per quarter respectively.

As in the case of oil shock, the reaction of all real variables, for both values of ω, are very similar to ones in the flexible price equilibrium. The intuition behind this result follows that of the oil shock discussed earlier.

4.3   Fixed exchange rate.

In this section we report results from similar simulations with a fixed exchange rate. The capital-mobility condition is then simply $i_t = i_t^F$. Now a country must give up an independent

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[26]For a more detailed discussion of dynamic responses see Kuralbayeva and Vines (2006)

monetary policy to keep the exchange rate fixed. Note that in this section we separate discussion of the simulation results for the case of a backward-looking Phillips curve from a forward-looking Phillips curve, as they are very different in the case of a fixed exchange rate regime.

4.3.1   Oil shock

Forward-looking Phillips curve ($\omega = 0.01$)

There are two features of impulse response functions (IRFs) in the fixed exchange rate regime, compared to flexible exchange rate regime, which are worth noting. First, short-run reactions of real variables and inflation are stronger in the fixed exchange-rate regime. Second, responses of real variables (except capital and investment in the non-traded sector) are hump shaped. The reason for such different propagation of the oil shock in the fixed exchange rate case can be seen as follows.

Given that the domestic interest rate is tied to the foreign rate and the fact that inflation rises on the impact of the shock, there is no short-run increase in the real interest rate in the country, as there was when the exchange rate could adjust. In fact, the real interest rate *declines.* An initial drop in the real interest rate stimulates investment in the non-traded sector, and this is a reason for the stronger increase in investment in the non-traded sector in the fixed exchange rate regime.

From households' side, the spending effect of a permanent rise in oil transfers is bigger in the fixed exchange rate case. Under a flexible exchange rate regime, the positive oil shock produces a considerable nominal appreciation, which has a significant impact on the spending effect of the shock. The spending effect (and thus consumption) is lower in the flexible exchange rate case than in the fixed exchange rate because increased demand for domestic currency is partly met through changes in the nominal exchange rate.

Higher demand for non-traded goods in the fixed exchange rate case generates stronger demand for labor, which pushes wages higher compared with the flexible exchange rate case. As wages rises more, real marginal costs increase more and the prices set by lucky firms are higher, which causes a bigger initial jump in inflation in the fixed exchange rate case compared with the flexible exchange rate regime.

The initial effects of the demand shock are larger on inflation in case of a fixed exchange rate compared with a flexible exchange rate. This is because part of the adjustment takes place via a change in the nominal exchange rate if the exchange rate is flexible.

In order to examine adjustment dynamics in response to the shock, we focus on three key elements of the adjustment process: the real interest rate, the real exchange rate, and the nominal exchange rate. As we discussed earlier, the real interest rate falls on the impact of the shock, which puts upward pressure on output in the non-traded sector. However, forward-looking behavior implies that the real interest rate is expected to be higher in subsequent periods, as they know the long-run value of the price level and expect prices to fall. So, inflation jumps up on the impact of the shock and then gradually falls as more and more price-setters adjust their prices to the new optimal level. The real interest rate is negative on the impact of the shock, but then starts rising, having a stabilizing effect. Moreover, there is another stabilizing channel, coming from real exchange rate.

As inflation remains positive throughout the adjustment period towards the long-run equilibrium level, the country's price level rises for some time and its real exchange rate declines (appreciates) for some time. This causes deterioration in net exports that results in a fall in demand for non-traded output. When demand falls low enough (precisely at the moment when the real interest rate returns to zero), prices start falling, and real exchange rate start depreciating. From here onwards, the dynamics of real variables are shaped by real exchange rate behavior only. Depreciation of real exchange rate will cause an improvement in net exports and that will cause an increase in the demand for non-traded output. Output increases gradually towards its long-run value. This explains the hump-shaped reaction of output in response to the shock. Similarly, hump-shaped responses of all other real variables are consequences of the same type of hump-shaped response of the real exchange rate. Such behavior of the real exchange rate is a result of the third channel of the adjustment process, or actually its absence: the nominal exchange rate. As discussed above, with an independent monetary policy with sticky prices, the nominal exchange rate carries out the burden of adjustment, resulting in a smooth response of the real exchange rate. In contrast, with a fixed exchange rate, prices do all the adjustment, which causes equivalent changes in the real exchange rate, reflected in a less smooth reaction of the latter. But because prices are sticky, an equivalent change in the real exchange rate would not be quick and immediate. This results in the hump-shaped behavior of the real exchange rate. For example, if prices were flexible, then the fixed exchange rate would be irrelevant since the relative price adjustment could be achieved by changes in prices and the real exchange rate would display the same pattern of response as in the flexible price model.

Backward-looking Phillips curve ($\omega = 0.9$).

The main feature of adjustment when there is a high proportion of backward-looking firms is that it is slow and cyclical.[27] The oscillations of the series of the non-traded sector are due to the evolution of backward-looking prices during the adjustment period towards steady state and the fixed exchange rate regime assumption. As we have seen above, backward-looking behavior does not modify significantly the responses of the economy to the shocks in the case of a flexible exchange rate regime. However with commitment to the fixed exchange rate, the country gives up independent monetary policy and backward-looking behavior changes the adjustment dynamics of the economy to the shock considerably.

To understand oscillatory responses to the shock, as before, we focus on three key elements of the adjustment mechanism: the real interest rate, the real exchange rate, and the nominal exchange rate. As the output gap is positive on the impact of the shock, inflation starts rising *gradually* (because of inertia) and the real interest rate starts falling for some time. This falling real interest rate would cause further output gains which could push prices further up and in turn cause the real interest rate to fall further, and so on. This could be destabilizing. This destabilizing real interest rate mechanism has become known as 'Walters critique', because of

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[27]Cycles are not desirable because they imply high welfare losses for the economy. In this paper we do not perform welfare analysis. However, within the context of EMU, Kirsanova et. al. (2006) derive a welfare function with second and higher order terms of variables, from which it implies that cyclicality will result in a higher welfare loss. This is consistent with Leitemo (2002), who evaluates social loss under different targeting regimes and varying degress of inflation persistence for an open-economy (within one-sector model) and finds that social loss is lower when there is less inflation persistence for most regimes considered.

the name of Sir A. Walters, who drew attention to the potentially destabilizing real interest rate response at the time when the UK entered the ERM.

However, the real exchange rate channel outweights the destabilizing effect coming from real interest rate movements. Temporary real appreciation, initially very sluggish, is great enough to stabilize the economy. Comparison of the paths of the real exchange rate in the face of oil shock in figures 6 and 14 confirms that the real exchange rate appreciates more in the case of a fixed exchange rate regime than in a flexible exchange rate case. So, real exchange rate appreciation reduces demand, by having a stronger effect than the real interest rate and demand starts falling after initial increase.

In addition, the presence of forward-looking firms (though a small proportion) can reinforce the stabilizing real exchange rate effect on the economy. This is because forward-looking consumers know that, as prices of non-traded goods are anchored by the price level outside the country, and if prices rise they would need to fall again, which would in due course cause the real interest rate to increase again. That would lead them to reduce their expenditure and thus demand. Thus, forward-lookingness in price setting helps to prevent instability coming from the real interest rate channel. The higher proportion of forward-looking firms, the lower consequences of the destructive Walters effects and a more smooth adjustment path. That is why, in most earlier papers on monetary policy in small open economies the 'Walters critique' problems are absent, because these papers assume forward-looking wage and price setters.

A gradual rise in inflation causes an increase in the price of non-traded goods, which will reach a level high enough to reduce demand and cause the output gap return to zero. However, at this point prices are still rising because of the rule-of-thumb behavior of backward-looking firms. This will lead to a further decline in the demand for non-traded goods, which will cause a further fall in the output gap. The output gap falls substantially causing a fall in the price of non-traded goods, and thus leading to a decline in inflation so that inflation reaches its long-run equilibrium level. However, at this point the output gap is below its potential level, so with an accelerationist Phillips curve[28] it is necessary for the inflation rate to fall further, and inflation will start falling below the steady state level. This explains the oscillatory response of the economy to an oil shock in the case of a fixed exchange rate regime. As in the case of the forward-looking Phillips curve discussed earlier, in the absence of a 'shock absorbing' role of the nominal exchange rate, the real exchange rate facilitates adjustment to the shock, resulting in an oscillatory reaction.

It is necessary to note that the problem of adjusting to the external shocks in a small open economy with fixed exchange rate and with a high proportion of backward-looking consumers and investors is similar, in many respects, to the problems faced by a small open economy with high degree of backwardness in the Phillips curve in responding to shocks in the monetary union. Westaway (2003) examines the key adjustment mechanisms available for a country in face of shocks inside and outside of monetary union. Our paper, in may respects, follows the same line of analysis. For example, our findings agree with his results, which show that no cycles are ensuing in a country with an independent monetary policy. Similarly without an independent

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[28]Under accelerationist Phillips curve, $\pi_t = \pi_{t-1} + \varsigma gap_t$ inflation tends to rise when output is above potential and fall when it is below.

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monetary policy, Westaway finds that output and the real exchange rate would follow a more oscillatory path compared to outside.

4.3.2   Risk-premium shock

Forward-looking Phillips curve ($\omega = 0.01$)

The short-run effects of the risk-premium shock is stronger in a fixed exchange rate regime compared with a flexible exchange rate. The intuition behind this result is similar to the case of the oil shock with a fixed exchange rate regime discussed earlier.

There is a stronger reaction of inflation to the shock compared with a flexible exchange rate. It is also should be noted that inflation behaves differently in the long-run from what would happen if the exchange rate was flexible. In that case inflation decreases in the new steady state. In the fixed exchange rate regime, inflation converges to its initial steady state level. The reason is that to keep the exchange rate fixed, in the new steady state the domestic interest rate must fall by the magnitude of the shock to remain tied to the world interest rate, while inflation anchored by the outside's inflation, goes back to its initial level.

Backward-looking Phillips curve ($\omega = 0.9$).

As in the case of an oil shock, a high proportion of backward-looking firms implies an oscillatory reaction of variables of the non-traded sector. The responses of these variables are modified by the rule of thumb behavior of backward-looking firms and should be analyzed in the same way as in the case of the oil shock above. In contrast to the flexible exchange rate case, inflation converges to its initial equilibrium level as the interest rate and inflation are tied to the world interest rate and foreign inflation in case of the fixed exchange rate.

5   Conclusion

The debate regarding the choice of exchange rate for an open economy has not yet been closed. In the presence of nominal rigidities, the conventional wisdom is that a flexible exchange rate regime is preferable to the fixed rate in the face of real shocks. A freely floating exchange rate serves as a real shock absorber, accommodating the needed adjustment in the real exchange rate without major real effects.

This paper attempts to shed light on one aspect of this debate. In a dynamic general equilibrium model with endogenous inflation persistence, we study the question of insulating properties of the alternative exchange rate regimes in response to terms of trade and risk-premium shocks. We show that the country's adjustment paths are slow and cyclical if there is a significant backward-looking element in the inflation dynamics with a fixed exchange rate. Such adjustment dynamics are moderated if there is a higher proportion of forward-looking price setters. In the case of an almost entirely forward-looking Phillips curve, the responses of variables become hump-shaped. The reason is that with a fixed exchange rate, prices do all the adjustment, which causes equivalent changes in the real exchange rate. But because prices are sticky, an equivalent change in the real exchange rate would not be quick and immediate. This results in the hump-shaped behavior of the real exchange rate as well as other real variables of the model.

In contrast, with an independent monetary policy, a freely floating exchange rate carries out the burden of adjustment, which results in a smooth response of the real exchange rate. Thus, a flexible exchange rate allows to escape inflation persistence and achieves a smooth response of real variables.

By introducing endogenous inflation persistence, we find support for the conventional wisdom regarding the insulating properties of a flexible exchange rate.

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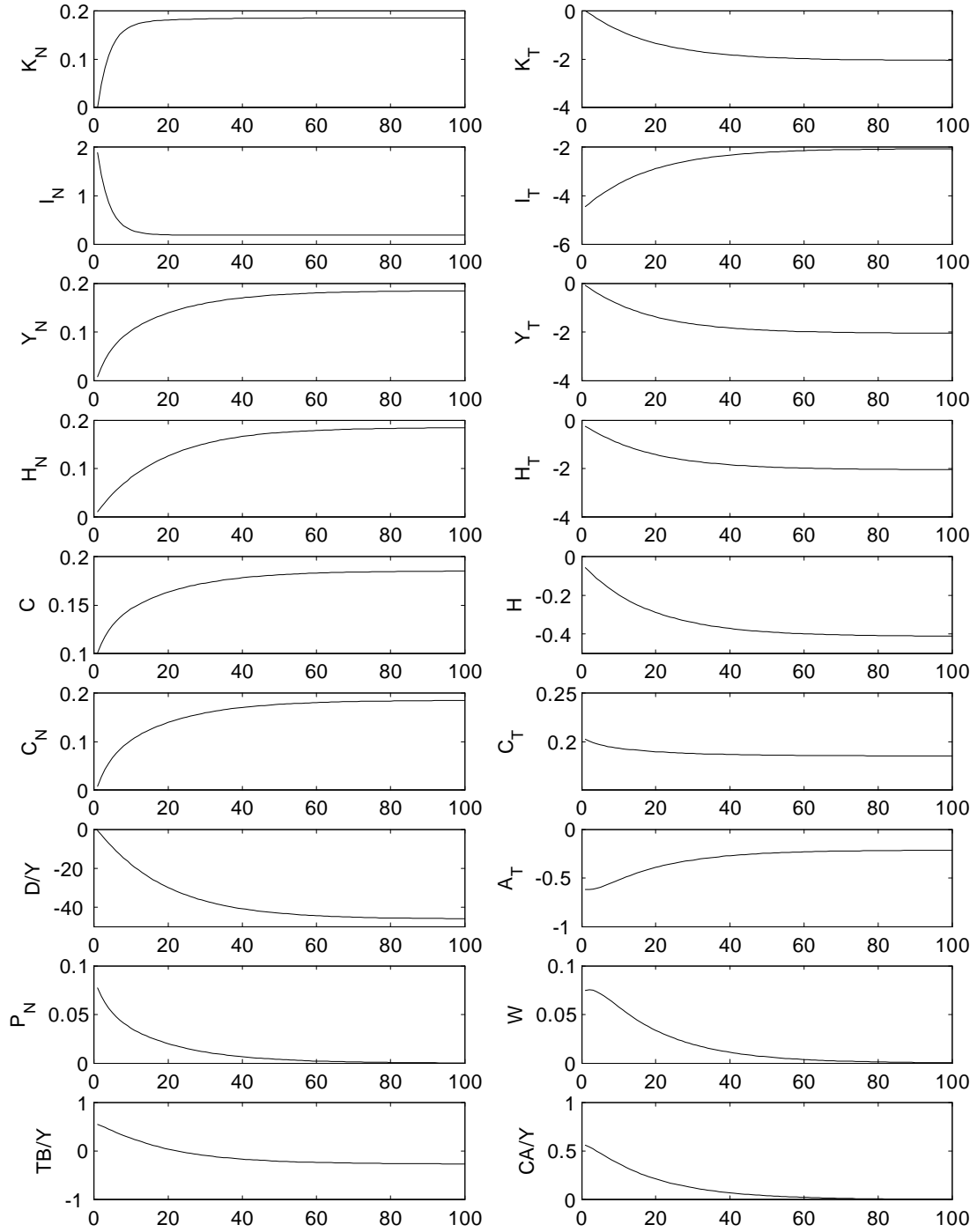
6   Appendix

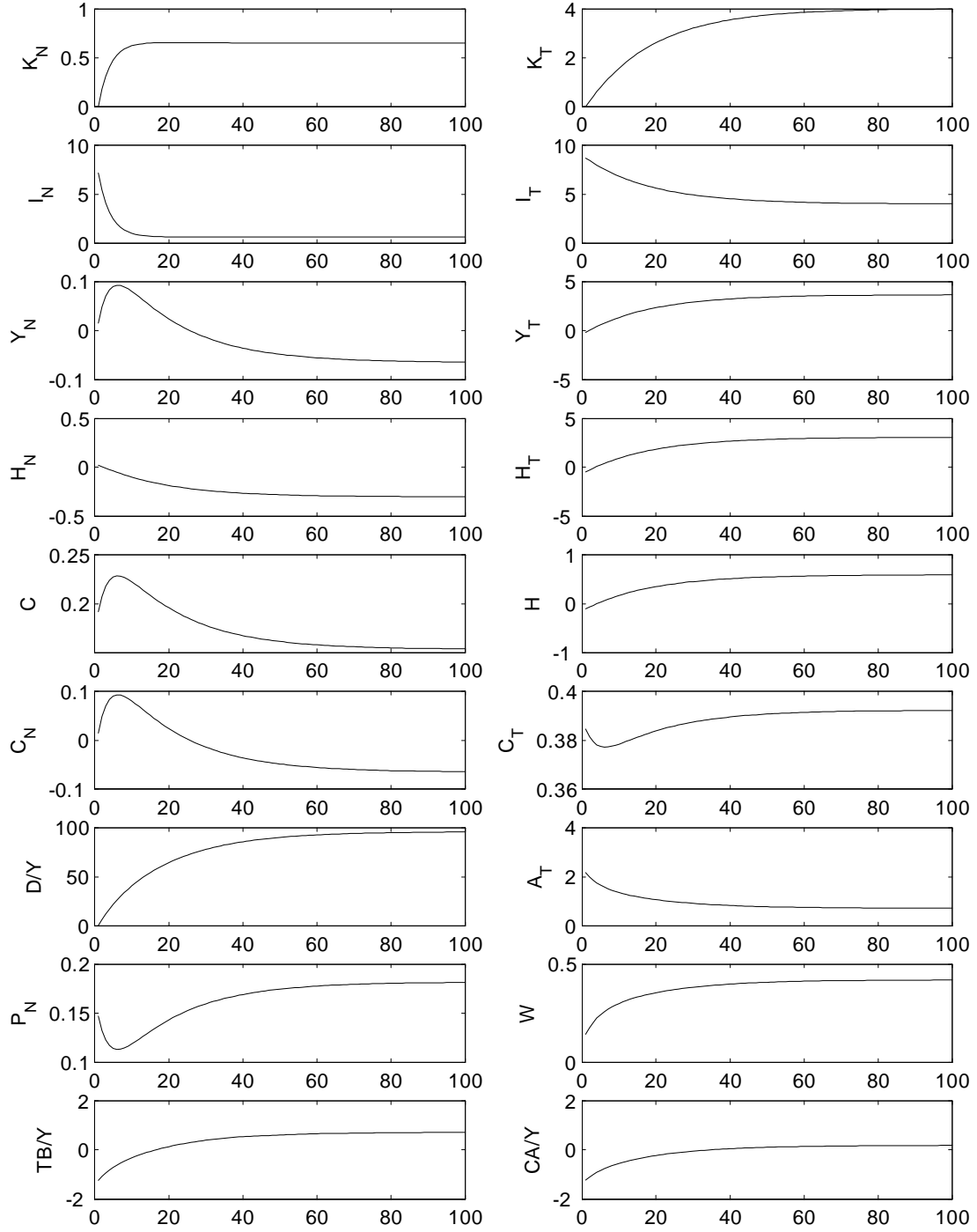Figure 1: Oil shock, flexible price model

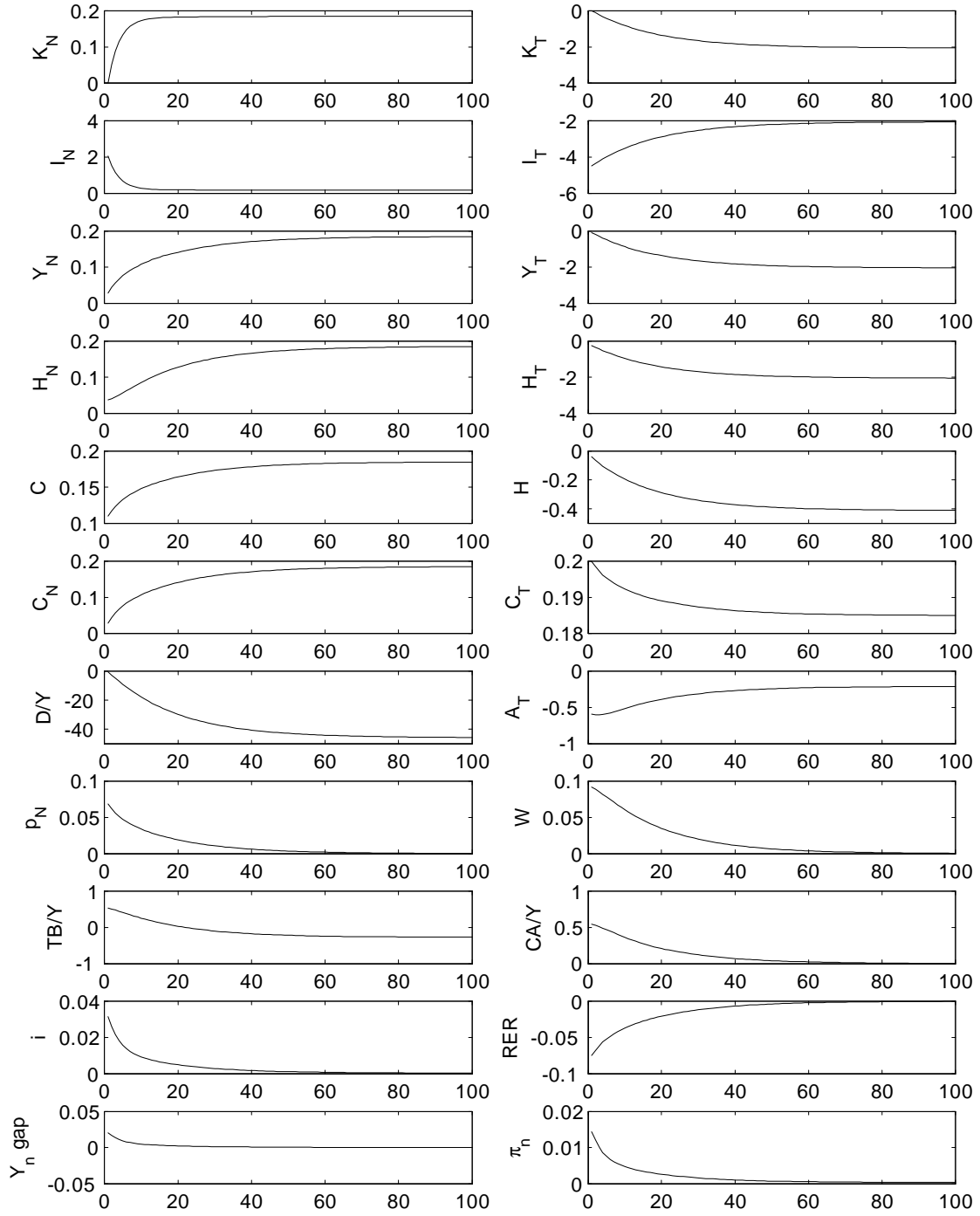Figure 2: Risk-premium shock, flexible price model

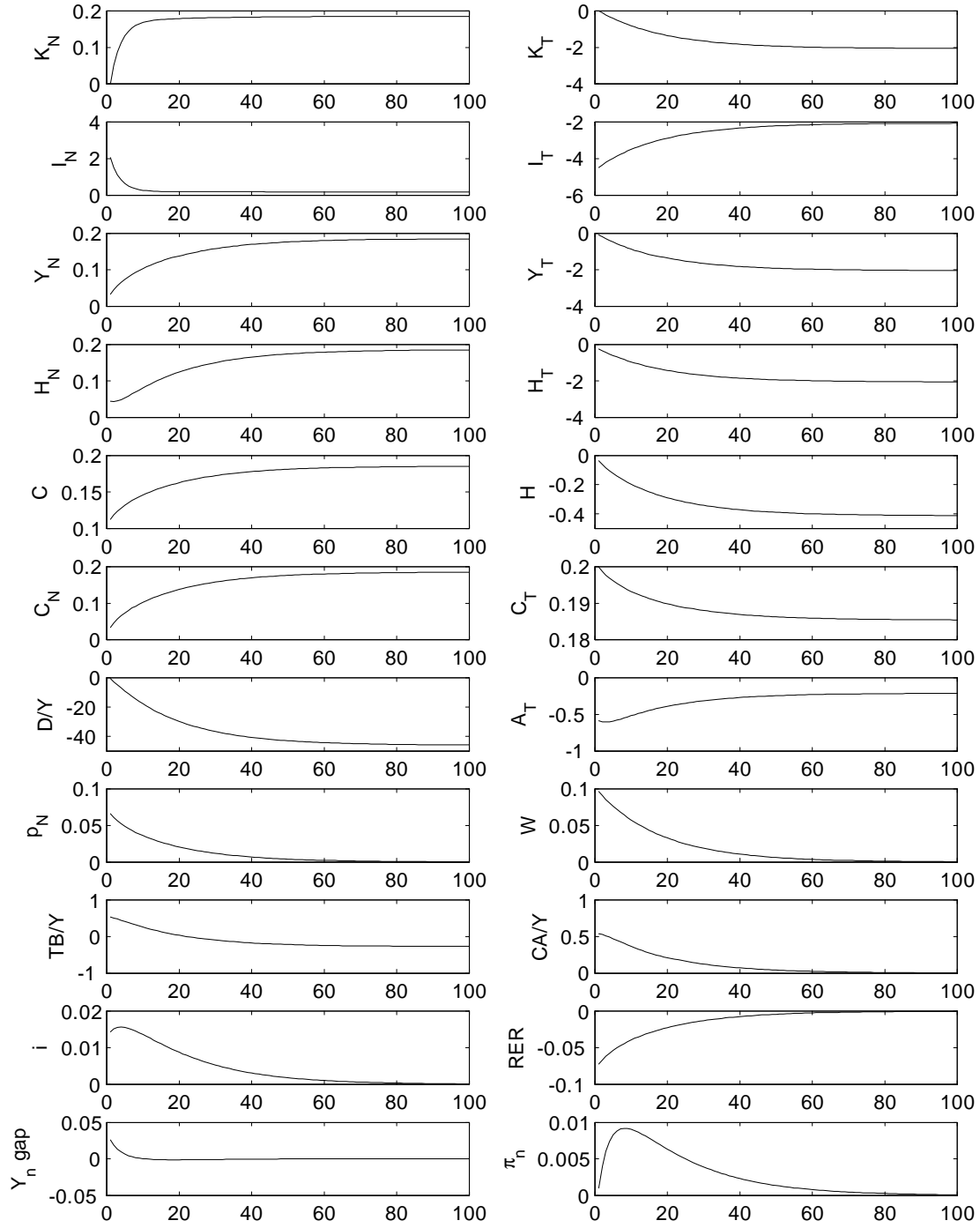Figure 3: Oil shock, $\omega = 0.01$, flexible exchange rate

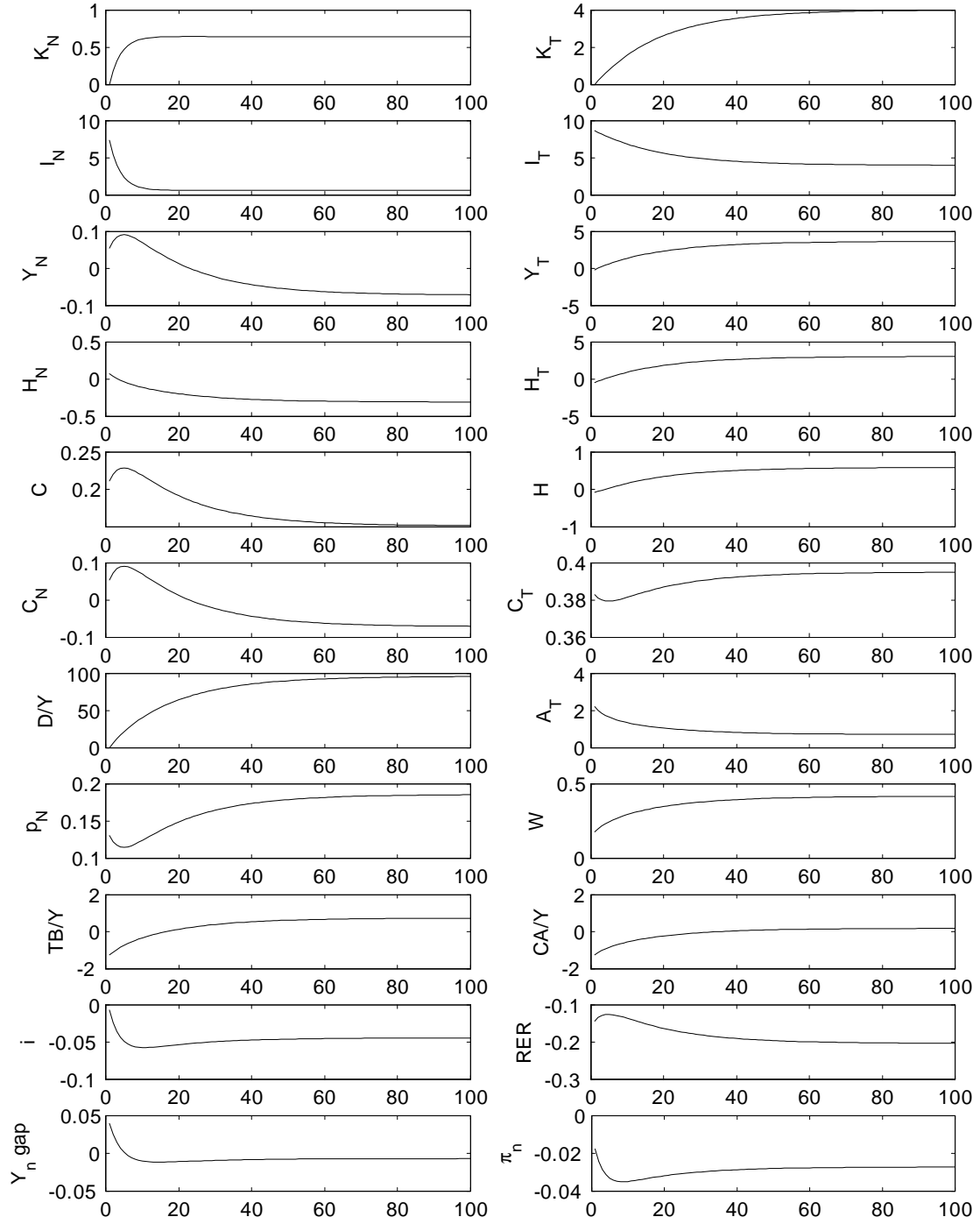Figure 4: Oil shock, $\omega = 0.9$, flexible exchange rate

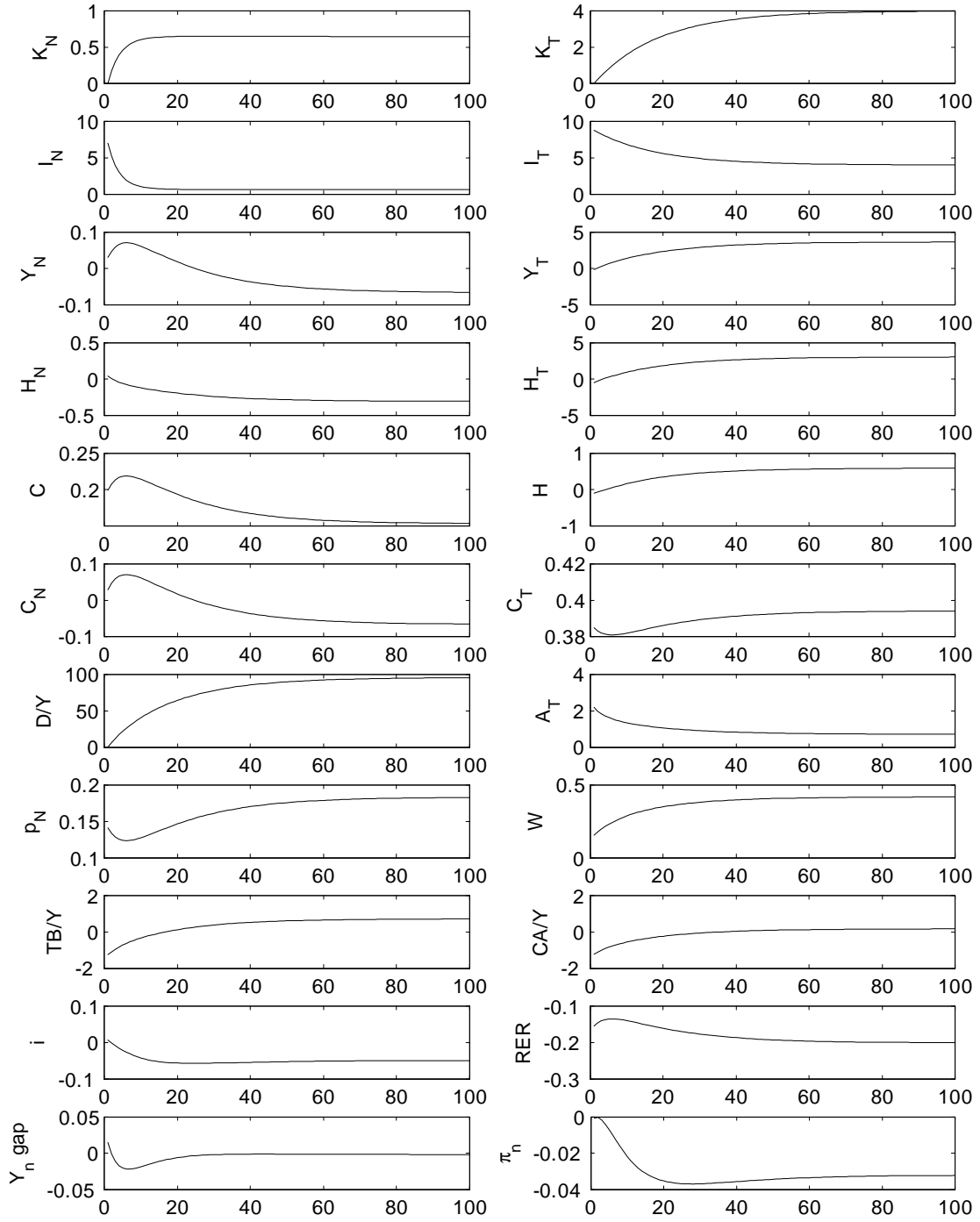Figure 5: Risk-premium shock, $\omega = 0.01$, flexible exchange rate

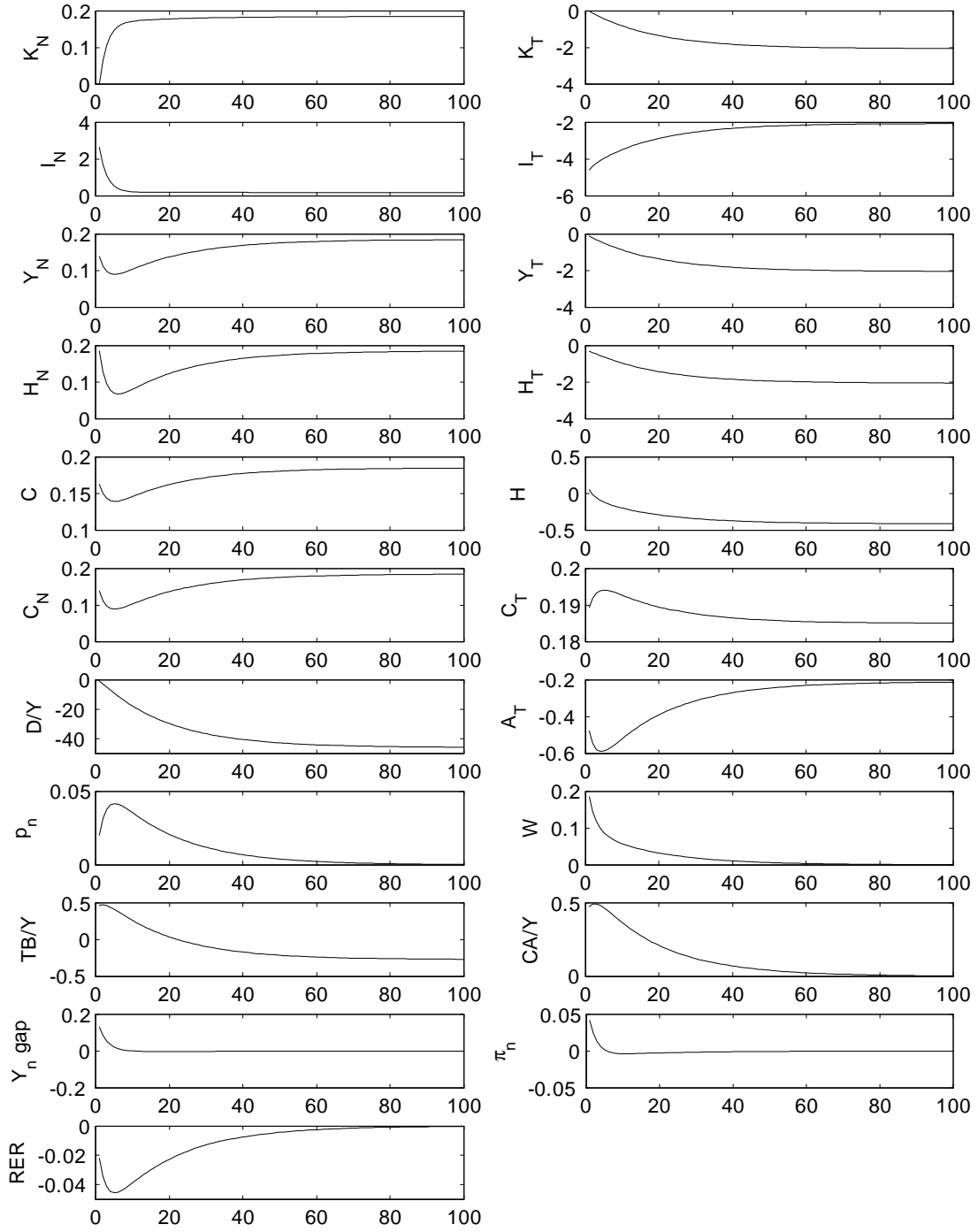Figure 6: Risk-premium shock, $\omega = 0.9$, flexible exchange rate

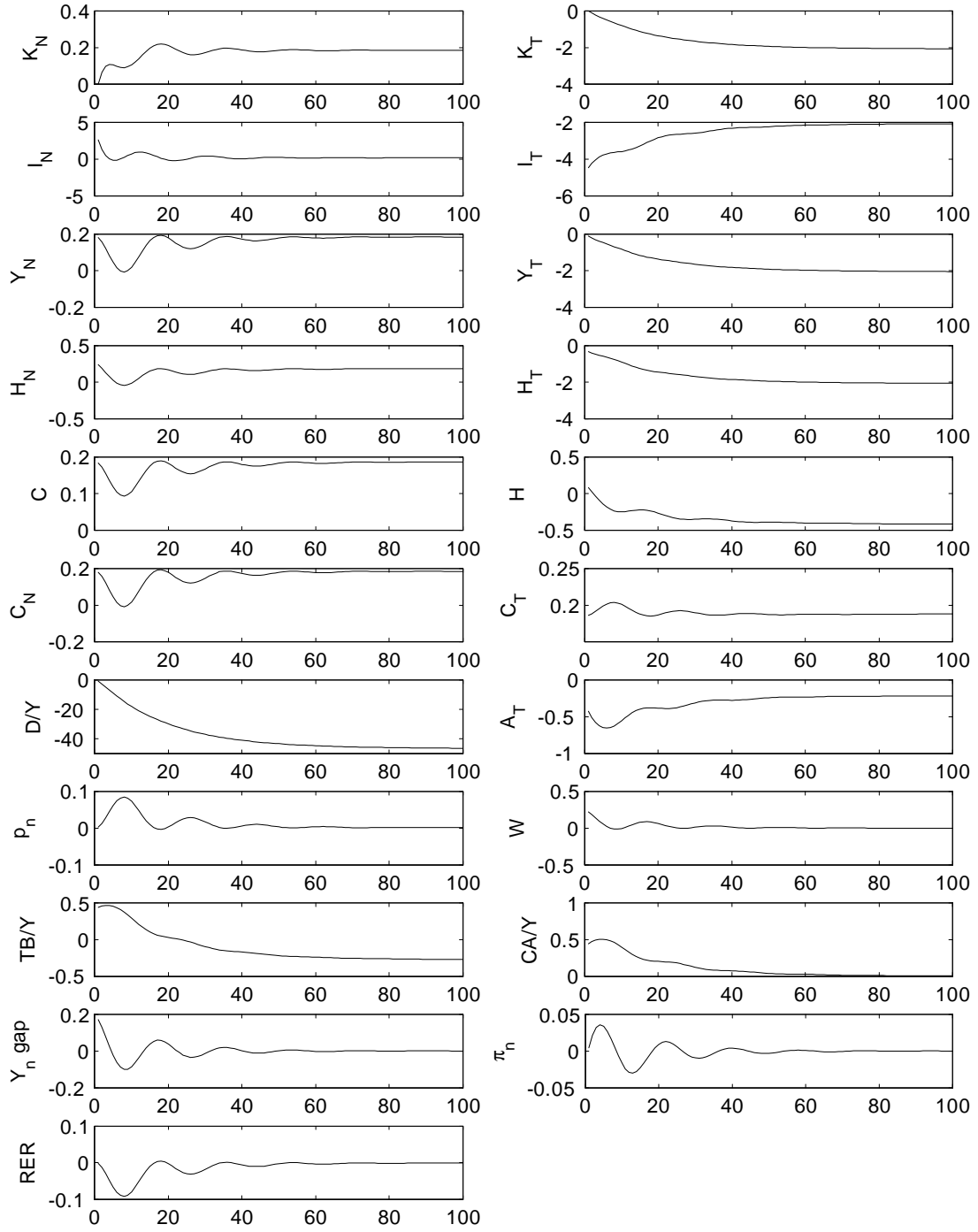Figure 7: Oil shock, $\omega = 0.01$, fixed exchange rate

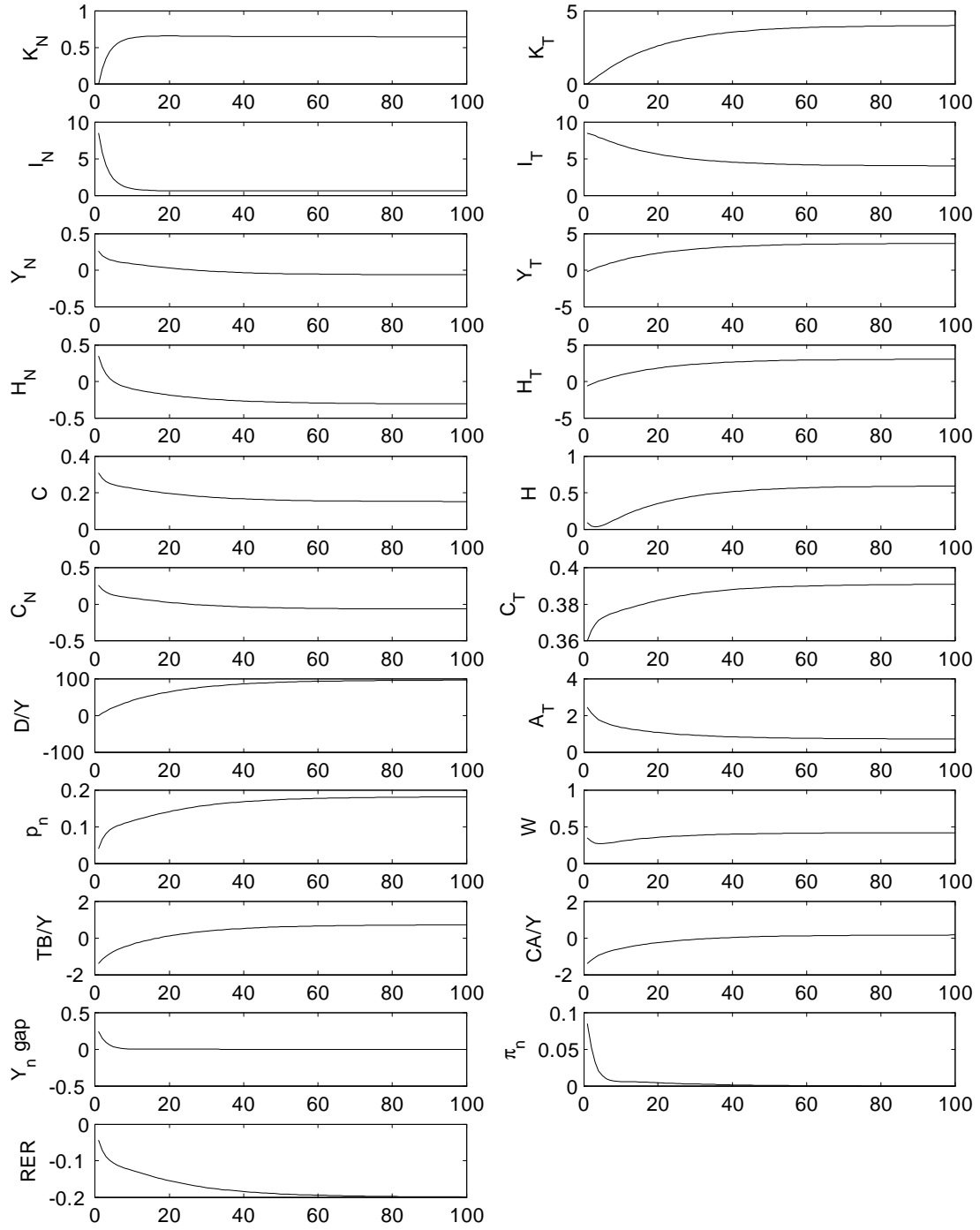Figure 8: Oil shock, $\omega = 0.9$, fixed exchange rate

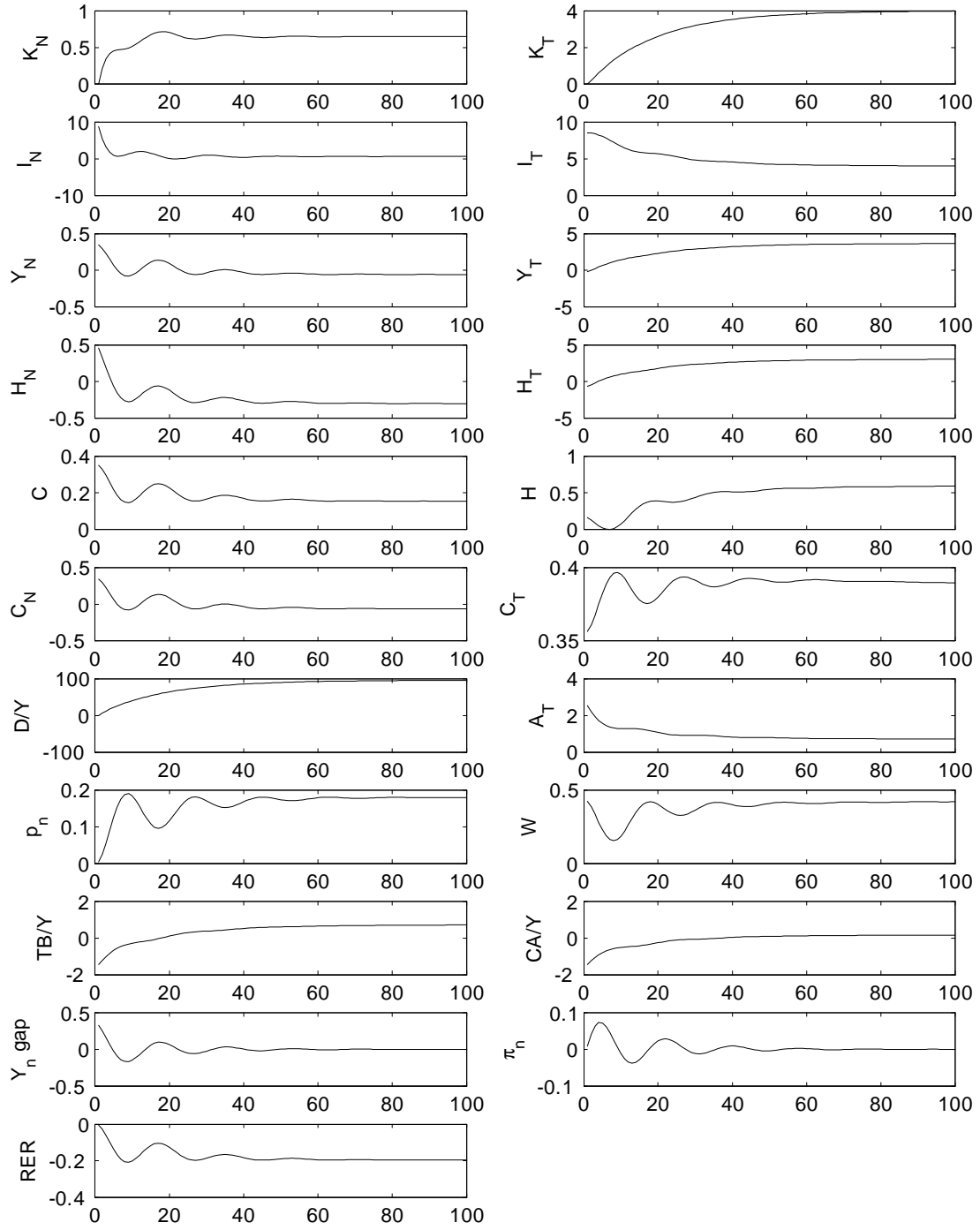Figure 9: Risk-premium shock, $\omega = 0.01$, fixed exchange rate

Figure 10: Risk-premium shock, $\omega = 0.9$, fixed exchange rate

7 Technical appendix

7.1 Production

In this subsection we focus on the structural equations arising from the representative firm's decision problem that concern production, labor and capital demand. In the next subsection we focus on pricing implications. So, we think about breaking the firm into two separate parts for planning purposes: production unit and pricing unit. First, the production unit takes, given the output level of the firm and the rental price of capital and wage rate (each firm operates under perfect competition in the inputs markets). Thus, each firm j in the non-traded sector determines its labor and capital demand so as to minimize its total costs. Second, the pricing unit determines the price of the firm's output, taking into account costs of production and demand conditions for the output.

$$\min_{K_{N,t}(j), H_{N,t}(j)} W_t H_{N,t}(j) + R_{N,t} K_{N,t}(j)$$

subject to $Y_{N,t}(j) = A_N K_{N,t}^{\alpha}(j) L_{N,t}^{1-\alpha}(j)$. To derive the first order consitions for firms optimization problem we write Lagrangian for the firm j in the non-traded sector as:

$$L = (W_t H_{N,t}(j) + R_{N,t} K_{N,t}(j)) + \lambda_t^f (Y_{N,t}(j) - A_N K_{N,t}^{\alpha}(j) H_{N,t}^{1-\alpha}(j))$$

so the first order conditions are:

$$\frac{\partial L}{\partial H_t(j)} = W_t - \lambda_t^f A_N (1-\alpha) K_{N,t}^{\alpha}(j) H_{N,t}^{-\alpha}(j) = 0 \tag{7.1}$$

$$\frac{\partial L}{\partial K_t(j)} = R_{N,t} - \lambda_t^f A_N \alpha K_{N,t}^{\alpha-1}(j) H_{N,t}^{1-\alpha}(j) = 0 \tag{7.2}$$

$$\frac{\partial L}{\partial \lambda_t^f} = Y_{N,t} - A_N K_{N,t}^{\alpha}(j) H_{N,t}^{1-\alpha}(j) = 0 \tag{7.3}$$

The lagrangian multiplier on the constraint is interpretable as nominal marginal cost, so $\lambda_t^f = MC_{N,t}(j)$, and (7.1)-(7.3) correspond to the following:

$$W_t = MC_{N,t}(j)(1-\alpha)\frac{Y_{N,t}(j)}{H_{N,t}(j)} \tag{7.4}$$

$$R_{N,t} = MC_{N,t}(j)\alpha\frac{Y_{N,t}(j)}{K_{N,t}(j)} \tag{7.5}$$

$$Y_{N,t}(j) = A_N K_{N,t}^{\alpha}(j) H_{N,t}^{1-\alpha}(j) \tag{7.6}$$

In the traded sector we assume perfect competition and flexible prices, so the cost of unit of production in that sector $MC_{T,t} = P_{T,t}$, such as the counterpart of equations (7.4)-(7.6) in traded sector is:

$$W_t = P_{T,t}(1-\gamma)\frac{Y_{T,t}}{H_{T,t}} \tag{7.7}$$

$$R_{T,t} = P_{T,t} \gamma \frac{Y_{T,t}}{K_{T,t}} \tag{7.8}$$

$$Y_{T,t} = A_T K_{T,t}^{\gamma} H_{T,t}^{1-\gamma} \tag{7.9}$$

7.2 Price setting by non-traded goods firms

Firms in the non-traded sector set their prices as monopolistic competitors. Pricing behavior is taken as in Rotemberg and Woodford (1997) and Steinsson (2003). We use Calvo (1983) sticky price specification and assume that the firm j changes its price with probability $(1 - \theta_N)$. That is, each period there is a constant probability $(1 - \theta_N)$ that the firm will be able to change its price, independent of past history[29]. We also assume that if prices are not reset, the old price is adjusted by a steady state inflation factor:

$$\Pi_{N,t} = P_{N,t}/P_{N,t-1} \tag{7.10}$$

Hence, even if the firm is not allowed to change its price, the latter grows at the same rate as trend inflation.

Those who re-set a new price (with probability $1 - \theta_N$), are split into backward-looking and forward-looking firms, in proportion ω, such that the aggregate index of prices set by the firms is

$$P_{N,t}^r = [(1-\omega)(P_{N,t}^F)^{1-\lambda} + \omega(P_{N,t}^B)^{1-\lambda}]^{\frac{1}{1-\lambda}} \tag{7.11}$$

Backward-looking firms set their prices according to the rule of thumb:

$$P_{N,t}^B = P_{N,t-1}^r \Pi_{N,t-1} (\frac{Y_{N,t-1}}{Y_{N,t-1}^n})^{\vartheta} \tag{7.12}$$

As in Galì and Gertler, this rule of thumb has the following features: (1) in a steady state equilibrium the rule is consistent with optimal behavior, that is $P_N^B = P_N^F$, (2) the price set in period t depends only on information dated $t-1$ or earlier.

7.2.1 Forward-looking price-setters

The problem of the firm j changing price at time t consists of choosing price $P_{N,t}^{new}(j)$ to maximize:

$$E_t \sum_{i=0}^{\infty} \theta_N^i \Phi_{t+i} [P_{N,t}^{new}(j) \Pi_N^i Y_{N,t+i}(j) - TC_{N,t+i}(j)] \tag{7.13}$$

subject to the total demand it faces:

$$Y_{N,t+i}(j) = (\frac{P_{N,t}^{new}(j)}{P_{N,t+i}} \Pi_N^i)^{-\lambda} Y_{N,t+i} \tag{7.14}$$

---

[29] Hence, the average time over which a price is fixed is given by $(1-\theta_N)1+\theta_N(1-\theta_N)2+...+\theta_N^{i-1}(1-\theta_N)i+... = $
$= (1-\theta_N)\sum_{i=0}^{\infty} i\theta_N^{i-1} = 1/(1-\theta_N)$. Thus, for example, with $\theta_N = 0.75$ in a quaterly model, prices are fixed on average for a year.

and where Φ_{t+i} is an appropriate stochastic discount factor, θ_N^i is the probability that the price $P_{N,t}^{new}(j)$ set for good j still holds i periods ahead, and $TC_{N,t+i}(j)$ represents total (nominal) costs. The discount factor relates to the way how the households value their future consumption relative to the current consumption, and we define the discount factor as:

$$\Phi_{t+i} = \beta^i \frac{\Lambda_{t+i}}{\Lambda_t} = \beta^i \frac{P_{t+i}^{-1} C_{t+i}^{-\sigma}}{P_t^{-1} C_t^{-\sigma}}$$

Cost minimizing behavior of the firm in non-traded sector yields the following expression for the total costs: $TC_{N,t+i}(j) = P_{N,t+i} mc_{N,t+i} Y_{N,t+i}(j)$, where $mc_{N,t+i} = MC_{Nt+i}/P_{N,t+i}$ represents real marginal costs.

The FOC of this maximization problem yields the following optimal price:

$$P_{N,t}^{new}(j) = \frac{\lambda}{\lambda - 1} \frac{E_t \sum_{i=0}^{\infty} (\theta_N \beta)^i \Lambda_{t+i} (P_{N,t}^{new}(j) \Pi_N^i / P_{N,t+i})^\lambda P_{N,t+i} mc_{N,t+i} Y_{N,t+i}}{E_t \sum_{i=0}^{\infty} (\theta_N \beta \Pi)^i \Lambda_{t+i} (P_{N,t}^{new}(j) \Pi_N^i / P_{N,t+i})^\lambda Y_{N,t+i}} \tag{7.15}$$

From (7.15) it is clear that all firms that reset their prices in period t, set it at the same level, so $P_{N,t}^{new}(j) = P_{N,t}^{new}$, for all $j \in [0,1]$, and we could omit subscript j. If we define two new variables

$$P_{N,t}^1 = E_t \sum_{i=0}^{\infty} (\theta_N \beta)^i \Lambda_{t+i} \left(\frac{P_{N,t}^{new} \Pi_N^i}{P_{N,t+i}}\right)^\lambda P_{N,t+i} mc_{N,t+i} Y_{N,t+i} \tag{7.16}$$

and

$$P_{N,t}^2 = E_t \sum_{i=0}^{\infty} (\theta_N \beta \Pi_n)^i \Lambda_{t+i} \left(\frac{P_{N,t}^{new} \Pi_N^i}{P_{N,t+i}}\right)^\lambda Y_{N,t+i} \tag{7.17}$$

then (7.15) can be rewritten as:

$$P_{N,t}^{new} = \frac{\lambda}{\lambda - 1} \frac{P_{N,t}^1}{P_{N,t}^2} \tag{7.18}$$

Both $P_{N,t}^1$ and $P_{N,t}^2$ can be expressed recursively that does away the use of infinite sums, such that:

$$P_{N,t}^1 = \Lambda_t \left(\frac{P_{N,t}^{new}}{P_{N,t}}\right)^{-\lambda} P_{N,t} mc_{N,t} Y_{N,t} + \beta \theta_N E_t P_{N,t+1}^1 \tag{7.19}$$

$$P_{N,t}^2 = \Lambda_t \left(\frac{P_{N,t}^{new}}{P_{N,t}}\right)^{-\lambda} Y_{N,t} + \beta \theta_N \Pi_N E_t P_{N,t+1}^2 \tag{7.20}$$

Finally, it is necessary to note that the optimal price set by forward-looking firms $P_{N,t}^F \equiv P_{N,t}^{new}$.

To obtain formula for the price set by forward-looking firms, we log-linearize expressions (7.16)-(7.18):

$$\widehat{p}_{N,t}^1 = (1 - \beta \theta_N)(-\sigma \widehat{C}_t - \lambda \widehat{p}_{N,t}^{new} + \widehat{p}_{N,t} + \widehat{mc}_{N,t} + \widehat{Y}_{N,t}) + \beta \theta_N E_t \widehat{p}_{N,t+1}^1 \tag{7.21}$$

$$\widehat{p}_{N,t}^1 = (1 - \beta \theta_N)(-\sigma \widehat{C}_t - \lambda \widehat{p}_{N,t}^{new} + \widehat{p}_{N,t} + \widehat{mc}_{N,t} + \widehat{Y}_{N,t}) + \beta \theta_N E_t \widehat{p}_{N,t+1}^1 \tag{7.22}$$

$$\widehat{p}_{N,t}^{new} = \widehat{p}_{N,t}^{1} - \widehat{p}_{N,t}^{2} \tag{7.23}$$

where $p_{N,t}^{new} = P_{N,t}^{new}/P_{N,t}$; $p_{N,t}^{1} = P_{N,t}^{1}$; $p_{N,t}^{2} = P_{N,t}^{2}P_{N,t}$. Substituting (7.21) and (7.22) into (7.23), we obtain the following formula for the forward-looking firms:

$$\widehat{p}_{N,t}^{F} = (1 - \beta\theta_N)\widehat{mc}_{N,t} + \beta\theta_N\widehat{p}_{N,t+1}^{F} + \beta\theta_N\pi_{N,t+1} \tag{7.24}$$

where we turn to the notation $\widehat{p}_{N,t}^{new} \equiv \widehat{p}_{N,t}^{F}$.

7.2.2   Aggregate price in the non-traded sector

The price index in the non-traded sector is given by:

$$P_{N,t} = (\int_0^1 P_{N,t}(j)^{1-\lambda}dj)^{1/(1-\lambda)} \tag{7.25}$$

which can be expressed as the average of all prices set i periods ago (in period $t - i$) that still hold in period t:

$$P_{N,t} = (\sum_{i=0}^{\infty}(1 - \theta_N)\theta_N^i(\Pi_N^i P_{N,t-i}^r)^{1-\lambda})^{1/(1-\lambda)} \tag{7.26}$$

where $(1 - \theta_N)\theta_N^i$ is the fraction of firms that last adjusted price $(P_{N,t-i}^r)$ i periods ago.

Using (7.11), expression in (7.26) can be rewritten recursively as:

$$
\begin{aligned}
P_{N,t} &= [(1 - \theta_N)(P_{N,t}^r)^{1-\lambda} + \theta_N(\Pi_N P_{N,t-1})^{1-\lambda}]^{\frac{1}{1-\lambda}} = \\
&= [(1 - \theta_N)(1 - \omega)(P_{N,t}^F)^{1-\lambda} + (1 - \theta_N)\omega(P_{N,t}^B)^{1-\lambda} + \theta_N(\Pi_N P_{N,t-1})^{1-\lambda}]^{\frac{1}{1-\lambda}} \tag{7.27}
\end{aligned}
$$

Linearization of equation above yields:

$$\pi_{N,t} = \frac{1 - \theta_N}{\theta_N}[(1 - \omega)\widehat{p}_{N,t}^F + \omega\widehat{p}_{N,t}^B] \tag{7.28}$$

where, as before, $\widehat{p}_{N,t}^F$ and $\widehat{p}_{N,t}^B$ denote percent deviations of $P_{N,t}^F/P_{N,t}$ and $P_{N,t}^B/P_{N,t}$ respectively, from their steady-state values of one.

7.2.3   Rule of thumb price-setters and Phillips curve

The rule of thumb price-setters use formula (7.12) to set the new price. The log-linearization of this equation straightforwardly yields:

$$\widehat{p}_{N,t}^B = \widehat{p}_{N,t-1}^r + \pi_{N,t-1} - \pi_{N,t} + \delta\widehat{y}_{N,t-1} \tag{7.29}$$

where the log-linearized version of the index of prices set at date $t - 1$ $(\widehat{p}_{N,t-1}^r)$ result of log-linearization of formula (7.11), and given by

$$\widehat{p}_{N,t-1}^r = (1 - \omega)\widehat{p}_{N,t-1}^F + \omega\widehat{p}_{N,t-1}^N \tag{7.30}$$

and $\widehat{y}_{N,t}$ denotes percent deviation of $Y_{N,t}/Y_{N,t}^n$ from steady state value of one.

So, now we have equation (7.24) that determines the price set by forward-looking firms, equation (7.29) that determines the price set by backward-looking firms and equation (7.28), thus, by doing manipulations similar to Steinsson (2003) (A.1)-(A.6), we eliminate $\widehat{p}_{N,t-1}^F$ and $\widehat{p}_{N,t-1}^N$ and obtain the following specification of the Phillips curve:

$$
\begin{aligned}
\pi_{N,t} &= \frac{\theta_N\beta}{\theta_N + \omega(1+\theta_N\beta-\theta_N)}E_t\pi_{N,t+1} + \frac{\omega}{\theta_N + \omega(1+\theta_N\beta-\theta_N)}\pi_{N,t-1} + \quad (7.31) \\
&+ \frac{\omega\vartheta(1-\theta_N)}{\theta_N + \omega(1+\theta_N\beta-\theta_N)}\widehat{y}_{N,t-1} - \frac{\beta\theta_N\omega\vartheta(1-\theta_N)}{\theta_N + \omega(1+\theta_N\beta-\theta_N)}\widehat{y}_{N,t} + \\
&+ \frac{(1-\beta\theta_N)(1-\omega)(1-\theta_N)}{\theta_N + \omega(1+\theta_N\beta-\theta_N)}\widehat{mc}_{N,t}
\end{aligned}
$$

Note that when $\omega = 0$ then the Phillips curve collapses to the standard forward-looking specification:

$$
\pi_{N,t} = \frac{(1-\beta\theta_N)(1-\theta_N)}{\theta_N}\widehat{mc}_{N,t} + \beta E_t\pi_{N,t+1} \qquad (7.32)
$$

When $\omega = 1$ then the Phillips curve takes the specification:

$$
\pi_{N,t} = \frac{\theta_N\beta}{1+\theta_N\beta}E_t\pi_{N,t+1} + \frac{1}{1+\theta_N\beta}\pi_{N,t-1} - \frac{1-\theta_N}{1+\theta_N\beta}[\beta\theta_N\vartheta\widehat{y}_{N,t} - \vartheta\widehat{y}_{N,t-1}] \qquad (7.33)
$$

7.3   Aggregation issue

In this subsection we focus on issues of aggregation in the non-traded sector. From cost minimization problem considered in the previous subsection we get:

$$
\frac{W_t}{R_{N,t}} = \frac{1-\alpha}{\alpha}\frac{K_{N,t}(j)}{H_{N,t}(j)} \Rightarrow \frac{1-\alpha}{\alpha}K_{N,t}(j) = H_{N,t}(j)\frac{W_t}{R_{N,t}} \qquad (7.34)
$$

Integrating second expression in (7.34) over all firms, and defining

$$
K_{N,t} = \int_0^1 K_{N,t}(j)dj; \quad H_{N,t} = \int_0^1 H_{N,t}(j)dj; \qquad (7.35)
$$

we get

$$
\frac{K_{N,t}(j)}{H_{N,t}(j)} = \frac{K_{N,t}}{H_{N,t}} \qquad (7.36)
$$

The production function for a given good j therefore becomes[30]

$$
Y_{N,t}(j) = A_N H_{N,t}(j)\left(\frac{K_{N,t}}{H_{N,t}}\right)^\alpha \qquad (7.37)
$$

which implies that aggregate supply in the non-traded sector is

$$
\int_0^1 Y_{N,t}(j)dj = A_N K_{N,t}^\alpha H_{N,t}^{1-\alpha} \qquad (7.38)
$$

---

[30]Note that (7.37) in conjuncture with (7.4) can be used to show that nominal marginal costs are identical across firms in the non-traded sector.

The demand for each differentiated good j is given by:

$$Y_{N,t}^D(j) = (\frac{P_{N,t}(j)}{P_{N,t}})^{-\lambda}\{C_{N,t} + a(\frac{P_{N,t}}{P_t})^{-\rho}[\phi_{N,t}K_{N,t} + \phi_{T,t}K_{T,t}]\} \equiv (\frac{P_{N,t}(j)}{P_{N,t}})^{-\lambda}Y_{N,t}^D \qquad (7.39)$$

so aggregate demand in the non-traded sector is given by:

$$\int_0^1 Y_{N,t}^D(j)dj = Y_{N,t}^D \int_0^1 (\frac{P_{N,t}(j)}{P_{N,t}})^{-\lambda}dj \qquad (7.40)$$

where

$$\Delta_t \equiv \int_0^1 (\frac{P_{N,t}(j)}{P_{N,t}})^{-\lambda}dj \qquad (7.41)$$

is a measure of relative price dispersion in the non-traded good sector. The steady state value of the dispersion is unity, while off-steady state it always ≥ 1, and rises with the variance of non-traded prices. As the equation (7.40) shows the higher variability of prices, given aggregate non-traded goods output, there will less aggregate consumption of the non-traded goods. Combining idendities (7.38) and (7.40), the overall non-traded goods market equilibrium equation is:

$$A_N K_{N,t}^\alpha H_{N,t}^{1-\alpha} = \Delta_t Y_{N,t}^D \qquad (7.42)$$

where $Y_{N,t}^D$ stands for aggregate demand of non-traded goods in the economy. Note that the aggregation introduces an additional term that deal with distribution of prices of non-traded goods. However, as shown by Yun (1996), Erceg et. al. (2000) and Christiano et. al. (2001) that term does not appear in the log-linear approximation of the aggregate constraint. We briefly summarize their argument here for the non-traded sector. For that, we define

$$\overline{P}_{N,t} \equiv (\int_0^1 P_{N,t}^{-\lambda}(j)dj)^{-1/\lambda} \qquad (7.43)$$

so that dispersion can be re-written as:

$$\Delta_t = (\frac{\overline{P}_{N,t}}{P_{N,t}})^{-\lambda} \qquad (7.44)$$

As for the aggregate price level in the non-traded sector, this price aggregate admits a recursive representation

$$\overline{P}_{N,t} = [(1 - \theta_N)(P_{N,t}^r)^{-\lambda} + \theta_N(\Pi_N \overline{P}_{N,t-1}]^{-1/\lambda} \qquad (7.45)$$

It can be easily seen that dispersion does not appear in the log-linearized version of the model. Log-linearization of aggregate price level of the non-traded sector, and the aggregate price index given by (7.45) yields the following expressions:

$$\widehat{P}_{N,t} = (1 - \theta_N)\widehat{P}_{N,t}^r + \theta_N\widehat{P}_{N,t-1} \qquad (7.46)$$

$$\widehat{\overline{P}}_{N,t} = (1 - \theta_N)\widehat{P}^r_{N,t} + \theta_N\widehat{\overline{P}}_{N,t-1} \tag{7.47}$$

while the log-linearized version of the price dispersion Δ_t is

$$\widehat{\Delta}_t = \lambda(\widehat{P}_{N,t} - \widehat{\overline{P}}_{N,t}) \tag{7.48}$$

So, substracting expression (7.46) from (7.47), and using expression in (7.48), we get that

$$\widehat{\Delta}_t = \theta_N\widehat{\Delta}_{t-1} \tag{7.49}$$

implying that if the economy is started from its steady state level, $\widehat{\Delta}_t = 0$ for all t, which we will consider hereafter.