Doctoral Thesis

“Essays on Open Economy, Inflation, and Labour Markets”

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Barcelona, November 2007 Alessia Campolmi

Introduction

In these last years there has been an increasing literature developing DSGE Open Economy Models with market imperfections and nominal rigidities. It is the so called "*New Open Economy Macroeconomics*". Up to now within this class of models (and differently from what it is happening in New Keynesian closed economy models) relatively little attention has been devoted to the labour markets. The first two chapters provide two cases where relaxing the assumptions of perfect competition and no frictions in the labour market is important for the question addressed. In the first chapter monopolistic competition in the labour market and nominal wage rigidities are introduced in an otherwise standard small open economy model. Within this framework we address the question of whether the presence of sticky wages provides a rational for Consumer Price Inflation targeting in the model. In the second chapter we introduce matching and searching frictions in the labour market and relate different labour market structures across European countries with differences in the volatility of inflation across the same countries. In the last chapter we use a two-country model with oil in the production function and price and wage rigidities to relate movements in wage and price inflation, real wages and GDP growth rate to oil price changes.

In particular, in chapter one the focus is on which measure of inflation should be used by the monetary authority as a target variable in a open economy context. Indeed, while there is common agreement on price inflation stabilization being one of the objectives of monetary policy, in an open economy two alternative measures of inflation coexist: domestic inflation and consumer price inflation (CPI inflation). Which one of the two should be the target variable? Most of the literature suggests that the monetary authority should try to stabilize domestic inflation. This is in sharp contrast with the practice of many inflation-targeting central banks which are using CPI inflation as a target variable. Using a small open economy model we show that CPI inflation targeting can be rationalized by the presence of sticky wages. After deriving the welfare function from a second order approximation of the utility function, we compute the optimal monetary policy under commitment and use it as a benchmark to compare the performance of different monetary policy rules. The rule performing best is the one targeting wage inflation and CPI inflation. Moreover, the performance of this rule is close to that of the optimal monetary policy with commitment.

In chapter two[1] the focus is on the Euro area. In particular, we start from the observation that despite having had the same currency for many years, EMU countries still have quite different inflation dynamics. We explore one possible reason: country specific labor market institutions, giving rise to different inflation volatilities. When unemployment insurance schemes differ, as they do in EMU, reservation wages react differently in each country to area-wide shocks. This implies that real marginal costs and inflation also react differently. We report evidence for EMU countries supporting the existence of a cross-country link over the cycle between labor market structures on the one side and real wages, real marginal costs and inflation on the other. We then build a DSGE model that replicates the data evidence.

Finally, chapter three focuses on the current increase in oil price. From the last quarter of 2001 to the third quarter of 2005 the real price of oil increased by 103%. Such an increase is comparable to the one experienced during the oil shock of 1973. At the same time, the behaviour of real GDP growth, Consumer Price inflation (CPI inflation), GDP Deflator inflation, real wages and wage inflation in the U.S in the 1970s was very different from the one exhibited in the 2000s. What can explain such a difference? Within a two-country framework where oil is used in production, two kinds of shocks are analyzed: (a) a reduction in oil supply, (b) a persistent increase in foreign productivity (as proxy for the experience of non-OECD countries in the last years). It is shown that, while the 1970s are consistent with a supply shock, the shock to foreign productivity generates dynamics close to the one observed in the 2000s.

[1] Joint work with Ester Faia.

Chapter 1

Which inflation to target? A small open economy with sticky wages

1.1 Introduction

The purpose of the present paper is to analyse which measure of inflation should be chosen as target variable in an open economy framework. In a closed economy context there is common agreement on price inflation stabilization being one of the main objectives of monetary policy. From the ad-hoc interest rate rule proposed by Taylor (1993), to the more recent New Keynesian literature deriving optimal monetary policy rules from the minimization of a microfounded loss function, the monetary instrument has to be chosen in order to match a given inflation target (among with other targets). However, in an open economy context two alternative measures of inflation coexist: domestic inflation and consumer price inflation (CPI inflation). For most of the OECD countries those two variables display different dynamics therefore, a relevant question is which one of these two should be used by the monetary authority as target variable. This is the question addressed in the paper.

With this purpose in mind, we develop a small open economy model similar to the one used by Galí and Monacelli (2005). The main difference with respect to that model is the introduction of sticky wages. Under this assumption the volatility of CPI inflation and the impossibility for some workers to adjust their wages in order to keep their markups at the desired level makes the stabilization of CPI relevant in this context. In particular, the assumption on wages has two main consequences: first, given the presence of wage rigidities, strict inflation targeting will no longer be optimal (as Erceg, Henderson and Levin (2000) show in a closed economy setup); second, fluctuations in CPI inflation will induce undesired fluctuations in wage mark ups and, therefore, in firms' marginal costs and domestic inflation.

The main result of the paper is that, reacting to changes in CPI inflation instead of focusing on targeting domestic inflation, the monetary authority will obtain better results in terms of stabilizing wage inflation and output gap. This makes it desirable to stabilize CPI inflation rather than domestic inflation. The importance of this result is that, differently from the existing open economy literature, it is in line with the practice of inflation-targeting central banks. Indeed, from an operational point of view, there seems to be an unanimous consensus among central banks on CPI inflation being the correct target. In particular, as stressed by Bernanke and Mishkin (1997), starting from 1990 the following countries have adopted an explicit target to CPI inflation: Australia, Canada, Finland, Israel, New Zealand, Spain, Sweden, UK. To this list we can add more recently Norway and Hungary. In the EMU, the European Central Bank has the objective to stabilize the Harmonized Index of Consumer Prices (HCPI) below 2%. In contrast, from a theoretical point of view, most of the literature suggests that the monetary authority should choose domestic inflation as target variable for inflation[1]. Hence, the contribution of the paper is to show that the introduction of sticky wages may help reconcile the workhorse model for monetary policy analysis in an open economy with the practice of many monetary

[1] A detailed review of the related literature is provided in the next section.

authorities.

Regarding the assumptions on which the results of the paper are built, there is strong empirical evidence of wage rigidity in the economy[2]. As underlined by Christiano, Eichenbaum and Evans (2005) and by Smets and Wouters (2003), the introduction of wage rigidity is a crucial assumption in order to improve the ability of the New-Keynesian models to match the data. Consequently, there is empirical evidence in favour of the importance of modelling also wage rigidity in order to obtain more reliable dynamics.

Solving the model under the assumption of sticky wages and looking at the Phillips Curve and the wage inflation equation a clear relation between domestic, CPI and wage inflation emerges. In particular, changes in the CPI inflation induce fluctuations in the wage markup and, therefore, increase the volatility of what can be considered an endogenous cost push shock i.e., the higher the volatility of CPI inflation, the bigger is the trade off faced by the monetary authority. Given that, it is clearly difficult to stabilize domestic inflation without stabilizing also CPI inflation. In order to obtain a more precise analysis of what a central bank should do, we derive the welfare function as a second order approximation of the utility function and then compute the fully optimal monetary policy under commitment. Using the optimal monetary policy as a benchmark, we then compare different interest rate rules. In the choice of possible targets for monetary policy we disregard the output gap because it cannot be considered a feasible target since it is not clear how to estimate the natural level of output. Therefore, we concentrate on the three variables: domestic inflation, CPI inflation and wage inflation. Among the three rules considered the one performing best is the wage inflation targeting rule. Between the two price inflation targeting rules, the one with CPI inflation outperforms the one targeting domestic

[2]For a review of the micro evidence of wage stickiness and of the importance of modelling wage rigidities together with price rigidities see Taylor (1998).

inflation. Several robustness checks on the main parameters are performed but the conclusion that under wage rigidity it is desirable to target CPI rather then domestic inflation does not change.

The structure of the paper is the following: section 1.2 presents the related literature, section 1.3 introduces the open economy model, section 1.4 presents the analysis of the welfare function, section 1.5 computes the optimal monetary policy under commitment, section 1.6 shows how different, implementable, monetary policy rules perform. Several robustness checks are included as well. Finally, section 1.7 concludes.

1.2 Related literature

Clarida, Galí and Gertler (2001) analyse a small open economy model with price rigidities and exogenous variations in wage markup. They find that, as long as there is perfect exchange rate pass-through, the target of the central bank should be domestic inflation. This is what they call "*the isomorphic result*" meaning that the form of the optimal interest rate rule is not affected by the consideration of being in an open economy. Openness only affects the aggressiveness with which the central bank should react to shocks. Therefore, the central bank should target domestic inflation and not CPI inflation. However, in their paper they do not explicitly model frictions in the labour market. They just assume an exogenous stochastic process for the wage markup. This is an important difference with respect to present paper because, even if assuming an exogenous process for the wage markup makes price stability no more optimal, the relation between fluctuations in the wage markup and fluctuations in CPI inflation is missing. A similar result is obtained in Galí and Monacelli (2005)[3]

[3]Under the assumptions of log utility in consumption and unit elasticity of substitution among foreign goods.

where strict domestic inflation targeting turns out to be the optimal monetary policy, consequently outperforming a CPI inflation targeting rule. Aoki (2001) shows that in a two-sector closed economy model with different price rigidities, more weight should be attributed to the inflation of the stickier sector[4]. He also shows that the extension of this result to a small open economy context implies that the monetary authority should target domestic inflation. Clarida, Galí and Gertler (2002) show, in a two-country model with sticky prices that, in the case of no coordination, the two monetary authorities should adjust the interest rate in response to domestic inflation. Benigno (2004) studies optimal monetary policy in a currency area using a two-country model with monopolistic competition and sticky prices in both regions. There are two independent fiscal authorities while there is only one monetary authority. The result is a generalization of the one obtained by Aoki (2001) in the closed economy, two-sector model. In the special case where prices are rigid only in one country, the central bank should stabilize domestic inflation in the country with sticky prices. In a more general case, where prices are rigid in both countries and the degree of price stickiness differs across the two regions, in the class of inflation targeting rules where the target is a weighted average of the domestic inflation in the two countries, higher weight needs to be attributed to the domestic inflation of the country with relatively more rigid prices. Still, as in the previous papers, the target variable is domestic inflation and not CPI inflation.

[4]Another closed economy model dealing with which inflation variable to target is the one by Huang and Liu (2005). In their model there are two sectors, one for the production of intermediate goods and one for the production of final goods. Intermediate goods are produced using labour as the only input while to produce final goods labour is combined with the intermediate goods. Prices are rigid in both sectors and there are sector specific shocks. The main conclusion is that an interest rate rule targeting both CPI inflation and PPI (producer price inflation) would attain better results than one seeking to stabilize CPI inflation. Anyway, as stressed by the authors in the paper, "the PPI [...] does not have a clear counterpart in an open economy setup" making a comparison with an open economy model difficult.

Differently from the aforementioned papers, Corsetti and Pesenti (2005) and DePaoli (2004) find that domestic inflation is not always the optimal target. But, the focus in those papers is not on which inflation to target but more on the general question of whether the policy should be inward-looking or outward-looking. Corsetti and Pesenti (2005) use a two-country model with firms' prices set one period in advance and incomplete pass-through to show that "inward-looking policy of domestic price stabilization is not optimal when firms' markups are exposed to currency fluctuations". DePaoli (2004) extends the welfare analysis for the small open economy of Galí and Monacelli (2005) allowing for a more general specification of the utility function and of the elasticity of substitution among domestically produced and foreign goods and finds that the monetary authority should target also the exchange rate, therefore supporting an outward-looking monetary policy. A paper dealing directly with the question of whether the monetary authority should target domestic or CPI inflation is the one by Svensson (2000). He uses a small open economy framework to analyse inflation targeting monetary policies and he underlines that "all inflation-targeting countries have chosen to target CPI...None of them has chosen to target domestic inflation". He assumes an ad-hoc loss function that includes both CPI inflation and domestic inflation in addition to other variables. The result of the model (that is not fully microfounded) is that flexible CPI inflation targeting is better than flexible domestic inflation targeting. Also in Monacelli (2005), the monetary authority is assumed to target CPI inflation instead of domestic inflation, in order to behave like many central banks do in practice, but the welfare function is not derived from first principles.

Summarizing, the papers claiming for an outward-looking monetary policy do not deal with the question of which measure of inflation should be chosen by the monetary authority. On the other side, papers focused directly on this question either show the importance of targeting domestic inflation instead of CPI inflation, or assume CPI inflation targeting without providing any rational for it other than the observed behaviour of central banks.

The contribution of the paper is to provide this rational as a consequence of the presence of wage stickiness, a highly plausible assumption.

1.3 The model

Following the standard set up laid out by Galí and Monacelli (2005), the world consists of a continuum $[0,1]$ of small, identical, countries. Each country is populated by a continuum $[0,1]$ of households which obtain utility from consumption and disutility from work. Households are allowed to consume both domestically produced and imported goods. Monopolistic competition and price stickiness is assumed in the goods market. Differently from what it is usually assumed in open economy models, labour market is modelled as monopolistically competitive and workers optimal decisions over wages are made under the assumption of Calvo staggering. It is worth noticing that, since complete markets and separable utility are assumed, households differ in the amount of labour supplied (consequence of the presence of sticky wages) but share the same consumption. Is is also assumed that the law of one price holds for individual goods at all times. From now on "h" refers to a particular household, "i" to a particular country and "j" to a specific sector. When no index is specified the variables refer to the home country.

1.3.1 Households

Household "h" maximizes:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U(C_t) + V(N_t(h)) \right] \tag{1.1}$$

where $N_t(h)$ is the labour supply and C_t is a consumption index which aggregate bundles of domestic and imported goods:

$$C_t \equiv \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{1.2}$$

where α represents the degree of openness, and $C_{H,t}$ and $C_{F,t}$ are two aggregate consumption indices, respectively for domestic and imported goods:

$$C_{H,t} \equiv \left[\int_0^1 C_{H,t}(j)^{\frac{\theta_p - 1}{\theta_p}} dj \right]^{\frac{\theta_p}{\theta_p - 1}} \tag{1.3}$$

$$C_{F,t} \equiv \left[\int_0^1 C_{i,t}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}} \tag{1.4}$$

$$C_{i,t} \equiv \left[\int_0^1 C_{i,t}(j)^{\frac{\theta_p - 1}{\theta_p}} dj \right]^{\frac{\theta_p}{\theta_p - 1}} \tag{1.5}$$

The parameter $\theta_p > 1$ represents the elasticity of substitution between two varieties of goods produced in the same country, while the parameter $\eta > 0$ represents the elasticity of substitution between home produced goods and goods produced abroad. Each household h maximizes (1.1) subject to a sequence of budget constraints[5]:

$$P_t C_t + E_t \left[Q_{t,t+1} D_{t+1} \right] \leq D_t + (1+\tau_w) W_t(h) N_t(h) + T_t \tag{1.6}$$

where $Q_{t,t+1}$ is the stochastic discount factor, D_t is the payoff in t of the portfolio held at the end of $t-1$, T_t is a lump-sum transfer (or tax) which also includes profits

[5]The results regarding the optimal allocation of expenditure across goods are not affected by the introduction of monopolistic competition in the labour market therefore, for a proof of how it is possible to derive the budget constraint in terms of aggregate variables, see Galí and Monacelli (2005)

resulting from ownership of firms, τ_w is a subsidy to labour income and P_t is the aggregate price index:

$$P_t \equiv \left[(1-\alpha)(P_{H,t})^{1-\eta} + \alpha(P_{F,t})^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{1.7}$$

$$P_{H,t} \equiv \left[\int_0^1 P_{H,t}(j)^{1-\theta_p} dj\right]^{\frac{1}{1-\theta_p}} \tag{1.8}$$

$$P_{F,t} \equiv \left[\int_0^1 P_{i,t}^{1-\eta} di\right]^{\frac{1}{1-\eta}} \tag{1.9}$$

$$P_{i,t} \equiv \left[\int_0^1 P_{i,t}(j)^{1-\theta_p} dj\right]^{\frac{1}{1-\theta_p}} \tag{1.10}$$

Each household supplies a differentiated labour service in each sector j, so that the total labour supplied by household h is given by $N_t(h) = \int_0^1 N_{t,h}(j)dj$. Consequently, he will maximize (1.1) w.r.t. $W_t(h)$ subject to the labour demand and the budget constraint. Given that the production function in each sector j is given by $Y_t(j) = A_t N_t(j)$ with $N_t(j) \equiv \left[\int_0^1 N_{t,j}(h)^{\frac{\theta_w-1}{\theta_w}} dh\right]^{\frac{\theta_w}{\theta_w-1}}$, the cost minimization problem of firms yields to the following demand for labour faced by individual h:

$$N_t(h) = \left[\frac{W_t(h)}{W_t}\right]^{-\theta_w} N_t \tag{1.11}$$

where $\theta_w > 1$ represents the elasticity of substitutions between workers, and the aggregate wage index is given by $W_t \equiv \left[\int_0^1 W_t(h)^{1-\theta_w} dh\right]^{\frac{1}{1-\theta_w}}$.

Wage decisions

Following Erceg et al. (2000), in each period only a fraction $(1-\xi_w)$ of households can reset wages optimally. For the fraction ξ_w of households that cannot optimize the wage will be the same as in the previous period:

$$W_t(h) = W_{t-1}(h) \tag{1.12}$$

Each household that can reoptimise in t will choose $W_t(h)$ considering the possibility that, with some probability, he will not be able to reoptimise any more in the future. Consequently, he will maximize (1.1) under (1.6) and (1.11) taking into account the probability of not being allowed to reoptimise in the future. The FOC of this optimisation problem with respect to $W_t(h)$ is:

$$E_t \sum_{T=0}^{\infty} (\beta\xi_w)^T \left[U_C[C_{t+T}] \frac{W_t(h)}{P_{t+T}} (1+\tau_w) \frac{\theta_w - 1}{\theta_w} + V_N[N_{t+T}(h)] \right] N_{t+T}(h) = 0 \tag{1.13}$$

From (1.13) it is clear that the solution $\widetilde{W_t}(h)$ will be the same for all households that reoptimise in t. To solve for the optimal wage we need first to log linearize (1.13) around the steady state:

$$E_t \sum_{T=0}^{\infty} (\beta\xi_w)^T \left[\widehat{\Psi}_{t+T} - \widehat{MRS}_{t+T}(h) \right] = 0 \tag{1.14}$$

where $\Psi_{t+T} = \frac{\widetilde{W}_t}{P_{t+T}}$ is the real wage, $MRS_t = -\frac{V_{N,t}}{U_{C,t}}$ and $\widehat{\Psi}_{t+T}$ and $\widehat{MRS}_{t+T}(h)$ are the log deviations from their levels under flexible prices. Rearranging terms it is possible to derive the following equation for the optimal wage:

$$\log \widetilde{W}_t = -log(1-\Phi_w) + (1-\beta\xi_w) E_t \sum_{T=0}^{\infty} (\beta\xi_w)^T \left[\log MRS_{t+T}(h) + \log P_{t+T} \right] \tag{1.15}$$

where $\log(1-\Phi_w) = \log(1+\tau_w) - \log(\mu_w)$ and $\mu_w = \frac{\theta_w}{\theta_w - 1}$ is the desired wage markup. Whenever $\tau_w = \frac{1}{\theta_w - 1}$, then $\Phi_w = 0$ and the fiscal policy completely eliminates the distortion caused by the presence of monopolistic competition in the supply of labour.

When $\tau_w < \frac{1}{\theta_w - 1}$, then $-\log(1-\Phi_w) > 0$ and a distortion is present in the economy[6]. From now on the following specification for the utility function is assumed:

$$U(C) + V(N) = \frac{C^{1-\sigma}}{1-\sigma} - \frac{N^{1+\varphi}}{1+\varphi} \tag{1.16}$$

where σ represents the relative risk aversion coefficient while φ is the inverse of the labour supply elasticity. Given this specification, and with some algebra, it is possible to derive the following expression:

$$\log \widetilde{W}_t = -\frac{(1-\beta\xi_w)}{1+\varphi\theta_w} \sum_{T=0}^{\infty} (\beta\xi_w)^T E_t[\widehat{\mu}_{w,t+T}] + \log(W_t) + \sum_{T=1}^{\infty} (\beta\xi_w)^T E_t \log \Pi_{w,t+T} \tag{1.17}$$

where $\widehat{\mu}_{w,t} = \log(W_t) - \log(P_t) - \log(MRS_t) + \log(1-\Phi_w)$ represents fluctuations in the wage markup. The optimal wage today will be higher the higher the expectations about future wages. Is there any role played by CPI inflation in the wage determination? If we expect and increase in the price level in the future (i.e. positive CPI inflation), we realize that our real wage will decrease, i.e. there will be a contraction in the wage markup (that could, eventually, become negative). As a consequence, when higher CPI inflation is expected, workers react setting a higher nominal wage today to contrast the fear of a reduction in their real wage tomorrow and in the near future.

The next step is to analyse the wage inflation equation. Given that the fraction $(1-\xi_w)$ of households that is allowed to reoptimise will choose the same wage, while for the others the wage is the same as in the previous period, the aggregate wage index is:

[6]Note that if $\frac{\theta_w}{\theta_w - 1} = 1 + \tau_w$ the fiscal policy is able to completely eliminate the distortion arising from labour markets. Following Woodford (2003), $1 - \Phi_w \equiv (1+\tau_w)\frac{\theta_w - 1}{\theta_w}$, where Φ_w represents the distortion in the economy. Whenever $\Phi_w > 0$ the level of employment in the flexible price equilibrium will be lower than the one that we would have without distortions. The welfare analysis will be done under the assumption $\Phi_w = 0$ but now the more general case is allowed for.

$$W_t = \left[(1-\xi_w)\widetilde{W}_t^{1-\theta_w} + \xi_w W_{t-1}^{1-\theta_w}\right]^{\frac{1}{1-\theta_w}} \tag{1.18}$$

The log linearized version of this equation is given by:

$$logW_t = (1-\xi_w)\log \widetilde{W}_t + \xi_w \log W_{t-1} \tag{1.19}$$

It is useful to rewrite (1.17) in the following way:

$$log\widetilde{W}_t - \beta\xi_w E_t \log \widetilde{W}_{t+1} = -\frac{1-\beta\xi_w}{1+\varphi\theta_w}\widehat{\mu}_{w,t} + (1-\beta\xi_w)\log W_t \tag{1.20}$$

From now on all the lower case letters denote the log of the variables. Combining (1.20) with (1.19) gives:

$$\pi_{w,t} = -\lambda_w \widehat{\mu}_{w,t} + \beta E_t[\pi_{w,t+1}] \tag{1.21}$$

where $\lambda_w = \frac{1-\xi_w}{\xi_w}\frac{1-\beta\xi_w}{1+\varphi\theta_w}$. Current wage inflation depends positively on the expected future wage inflation and negatively on the deviation of the markup from its frictionless level. In particular when $\widehat{\mu}_{w,t} > 0$ the markup charged is higher than its optimal level and that is way wages respond negatively to a positive $\widehat{\mu}_{w,t}$. This result is consistent with the one obtained in Galí (2003) in the closed economy case. It is important to note, in order to understand the future results, that fluctuations in CPI inflation will induce fluctuations in wage inflation through their impact on the wage mark-up. Indeed, as explained before, changes in CPI inflation will induce changes in the real wage and therefore will translate into fluctuations of $\widehat{\mu}_{w,t}$.

Having discussed the wage decisions, we move to the consumption choice which is standard.

Consumption Decisions

Maximizing (1.1) with respect to consumption and asset holdings subject to (1.6), leads to the standard Euler Equation:

$$\beta R_t E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right] = 1 \tag{1.22}$$

with $R_t = \frac{1}{E_t[Q_{t,t+1}]}$ gross nominal interest rate.

The next step is to study the firm's problem.

1.3.2 Firms

The production function of a domestic firm in sector j is given by:

$$Y_t(j) = A_t N_t(j) \tag{1.23}$$

with $a_t \equiv \log(A_t)$ and

$$a_{t+1} = \rho_a a_t + \varepsilon_{a,t}. \tag{1.24}$$

where $\varepsilon_{A,t}$ is an i.i.d shock with zero mean. The aggregate domestic output is given by:

$$Y_t = \left[\int_0^1 Y_t(j)^{\frac{\theta_p - 1}{\theta_p}} dj \right]^{\frac{\theta_p}{\theta_p - 1}} \tag{1.25}$$

Up to a first order approximation Galí and Monacelli (2005) demonstrate that:

$$y_t = a_t + n_t \tag{1.26}$$

In each period only a fraction $(1 - \xi_p)$ of firms can reset prices optimally.

Given that the elasticity of substitution between varieties of final goods is $\theta_p > 1$, the markup that each firm would like to charge is $\mu_p = \frac{\theta_p}{\theta_p - 1}$. Assuming the presence of a subsidy τ_p to the firm's output, optimal price-setting of a home firm j must satisfy the following FOC:

$$E_t \sum_{T=0}^{\infty} \xi_p^T Q_{t,t+T} Y_{t+T}(j) \left[(1+\tau_p) \frac{\theta_p - 1}{\theta_p} P_{H,t}(j) - MC_{t+T} \right] = 0 \tag{1.27}$$

where MC_t represents the nominal marginal cost. Like for wages, it is useful to define $1 - \Phi_p \equiv (1+\tau_p)\frac{\theta_p - 1}{\theta_p}$, where Φ_p indicates the distortion due to monopoly power on the firm side that is still present in the economy after the intervention of the fiscal authority. If the fiscal authority optimally chooses τ_p in order to exactly offset the monopoly distortion then $\Phi_p = 0$. If $\Phi_w > 0$ and/or $\Phi_p > 0$ then the flexible price allocation will deliver an output and an employment level lower than the natural ones. From the log-linear approximation of (1.27) around the steady state it is possible to derive the standard log-linear optimal price-setting rule:

$$\widetilde{p}_{H,t} = -\log(1 - \Phi_p) + (1 - \beta\xi_p) E_t \sum_{T=0}^{\infty} (\beta\xi_p)^T [mc_{t+T} + p_{H,t}] \tag{1.28}$$

where $\widetilde{p}_{H,t}$ represents the (log) price chosen by the firms that are allowed to reoptimise in t, and mc_t represents the (log) real marginal cost.

1.3.3 Equilibrium Conditions

To close the model some relations between home and foreign variables are needed. A "star" will be used to denote world variables. The derivation of the following equations[7] can be found in Galí and Monacelli (2005):

$$C_t^* = Y_t^* \tag{1.29}$$

[7]All these relations, with the only exception of (1.29) that is an exact relation, hold exactly only under the assumption that $\sigma = \eta = 1$. Otherwise they hold up to a first order approximation.

$$c_t = c_t^* + \frac{1-\alpha}{\sigma} s_t \tag{1.30}$$

where $S_t \equiv \frac{P_{F,t}}{P_{H,t}}$ are the effective terms of trade and (1.30) represents the international risk sharing condition. The market clearing condition is given by:

$$Y_t = C_t S_t^{\alpha} \tag{1.31}$$

The world output is assumed to follow an exogenous law of motion:

$$y_{t+1}^* = \rho_y y_t^* + \varepsilon_{y,t}. \tag{1.32}$$

with $\varepsilon_{y,t}$ i.i.d. shock with zero mean. The terms of trade can be expressed also in function of the aggregate and the home price indexes:

$$\alpha s_t = p_t - p_{H,t} \tag{1.33}$$

Under the assumption that the law of one price holds:

$$s_t = e_t + p_t^* - p_{H,t} \tag{1.34}$$

where $e_t \equiv \int_0^1 e_{i,t} di$ represents the log of the nominal effective exchange rate, $p_{i,t}^i \equiv \int_0^1 p_{i,t}^i(j) dj$ is the log of the domestic price level of country i and $p_t^* \equiv \int_0^1 p_{i,t}^i di$ represents the world price level.

The relation between the home output and the world output is given by:

$$s_t = \sigma_\alpha (y_t - y_t^*) \tag{1.35}$$

with $\sigma_\alpha \equiv \frac{\sigma}{1-\alpha+\alpha\omega} > 0$ and $\omega \equiv \sigma\eta + (1-\alpha)(\sigma\eta - 1)$.

1.3.4 The New Keynesian Phillips Curve (NKPC)

The relation between domestic inflation and real marginal cost is not affected by the presence of sticky wages:

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda \widehat{mc}_t \tag{1.36}$$

with $\lambda \equiv \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p}$ and with $\widehat{mc}_t$ denoting log deviations of the real marginal cost from its level in the absence of nominal rigidities (i.e. $\widehat{mc}_t = mc_t - mc$ with $mc = \log(1-\Phi_p)$). The presence of sticky wages leads to an additional term in the equation relating the marginal cost with the output gap (the derivation can be found in appendix A.1):

$$\widehat{mc}_t = (\sigma_\alpha + \varphi)(y_t - \overline{y}_t) + \widehat{\mu}_{w,t} \tag{1.37}$$

where $\overline{y}_t$ represents the natural level of output i.e., the output that would arise when prices and wages are flexible.

When wages are fully flexible, like in Galí and Monacelli (2005), $\widehat{\mu}_{w,t} = 0$ and we have the standard New Keynesian Phillips Curve (NKPC):

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda(\sigma_\alpha + \varphi)(y_t - \overline{y}_t) \tag{1.38}$$

In this context there is no trade off between closing the output gap and inflation stabilization. If the fiscal authority sets the subsidies in such a way to eliminate the steady state distortions due to monopolistically competitive labour and goods market, then the monetary authority can reach the first best allocation by setting to zero domestic inflation in every period. Galí and Monacelli (2005) show that, if the Central Bank follows a simple interest rate rule, then the one targeting at domestic inflation performs better than the one targeting at CPI inflation. As argued in the introduction, this theoretical result is in contrast with the practice of most Central

Banks, which are using CPI inflation as the relevant variable when setting the interest rate.

When wages are sticky, the wage markup will fluctuate over the cycle and the NKPC for a small open economy with both price and wage rigidities become:

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda(\sigma_\alpha + \varphi)(y_t - \overline{y}_t) + \lambda\widehat{\mu}_{w,t} \tag{1.39}$$

Even assuming that the only distortions left in the economy are the ones generated by the presence of nominal rigidities (i.e. the fiscal authority sets the subsidies in order to eliminate the steady state distortions), clearly, as in Erceg et al. (2000), it is not possible to stabilize at the same time domestic inflation, wage inflation and output gap and the flexible price allocation is no longer a feasible target. The question is then whether it is still true that an interest rate rule targeting domestic inflation is the one that performs best. The answer to this question is no. In particular, we will show that sticky wages rationalize CPI inflation targeting therefore reconciling the theory with Central Banks practice. Since nominal wages are sticky, fluctuations in CPI inflation will translate into fluctuations of the real wage and, therefore, into fluctuations of $\widehat{\mu}_{w,t}$ i.e., the more volatile is CPI inflation, the more volatile will be $\widehat{\mu}_{w,t}$. Since this variable acts like an endogenous cost push shock in the NKPC, reducing the volatility of CPI inflation helps reducing the trade off faced by the monetary authority. Looking jointly at equations (1.21) and (1.39) it emerges clearly that reducing the volatility of CPI inflation will first, reduce the volatility of wage inflation and, second, reduce the trade off faced by the monetary authority therefore reducing the volatility of domestic inflation and of the output gap. This is not the case when the monetary authority targets domestic inflation. This is the intuition of the main mechanism at work. To prove it, in the next section we will derive the welfare function from a second order approximation of the utility of the representative household. The welfare function will then be used to study the behavior of the economy under optimal monetary policy. Finally, using the results under optimal monetary policy as benchmark, the welfare losses obtained using different, implementable, policy rules will be compared.

Before moving to the next section it may be useful to note that the simple introduction of an exogenous cost push shock like for example in Clarida et al. (2001) does not do the same job. Indeed, while it does introduce a trade off in the Phillips Curve so that strict inflation targeting is not optimal anymore, such a trade off is exogenous and therefore not related to the behaviour of CPI inflation. In this context, an interest rate rule targeting at domestic inflation clearly outperform the one targeting CPI inflation. This shows that the use of exogenous cost push shock in an open economy framework can not really be considered a short cut for sticky wages if we want to derive monetary policy prescriptions.

1.4 Welfare function

In the present model there are five distortions: monopolistic power in both goods and labour markets; nominal rigidities in both wages and prices; incentives to generate an exchange rate appreciation. The first four would be present in a closed economy as well. The last one is specific to the open economy framework and has been first emphasised by Corsetti and Pesenti (2001). In particular, a monetary expansion has two consequences in this context: it increases the demand for domestically produced goods (increasing the disutility from working) and it deteriorates the terms of trade of domestic consumers. Therefore, the monetary authority may have the incentive to generate an exchange rate appreciation, even at the cost of a level of output (employment) lower than the optimal one. As a consequence, while in a closed economy framework it is enough to require $\Phi_w = \Phi_p = 0$ to ensure that the flexible price allocation will coincide with the optimal one, this is no more true in an open economy. We, therefore, need to solve the planner's problem and then set the subsidies accordingly.

In order to keep the model tractable when doing welfare analysis, the simplifying assumption $\sigma = \eta = 1$ (i.e. log utility in consumption and unit elasticity of substitution between home produced and foreign produced goods) is made. In this case the equilibrium conditions derived in 1.3.3 hold exactly and maximizing (1.1) under the production function $Y_t = A_t N_t$, (1.30) and (1.31) leads to the following FOC:

$$-\frac{U_N}{U_C} = (1-\alpha)A^{1-\alpha}N^{-\alpha}(Y^*)^{\alpha} \tag{1.40}$$

The solution is a constant, optimal, level of employment $N = (1-\alpha)^{\frac{1}{1+\varphi}}$. Let us now analyse under which conditions the flexible price equilibrium delivers the optimal allocation. Under flexible prices and wages, in every period $\widehat{\mu}_{w,t} = \widehat{mc}_t = 0$. Combining these two conditions together with the equilibrium conditions, it is possible to derive:

$$N_t^{1+\varphi}\frac{\mu_w}{1+\tau_w} = \frac{1+\tau_p}{\mu_p} \tag{1.41}$$

Once having substituted for the optimal level of N, (1.41) tells us how the two subsidies should be set in order to attain the optimal allocation in the flexible prices equilibrium[8].

As in Erceg et al. (2000),all households have the same level of consumption but different levels of labour. For this reason, when computing the welfare function, we need to average the disutility of labour across agents:

$$W_t = U(C_t) + \int_0^1 V(N_t(h))dh \tag{1.42}$$

The details of the derivation of the welfare function as a second order approximation of the utility of the representative consumer can be found in Appendix A.2. The

[8]In the simulations, $\Phi_w = 0$ and consequently, $1 - \Phi p = 1 - \alpha$.

expected welfare loss in a small open economy with both price and wage rigidities is given by:

$$L = -\frac{1-\alpha}{2}\left[(1+\varphi)Var(x_t) + \frac{\theta_p}{\lambda}Var(\pi_{H,t}) + \frac{\theta_w}{\lambda_w}Var(\pi_{w,t})\right] \quad (1.43)$$

where $x_t \equiv y_t - \overline{y}_t$ represents the output gap.

In the presence of only price rigidity (like Galí and Monacelli (2005)) the loss is function only of the volatility of the output gap and of domestic inflation. The introduction of wage rigidity adds a new term, the volatility of wage inflation.

The next step is to analyse the behaviour of the economy under the fully optimal monetary policy with commitment. Then, using the results under optimal monetary policy as a benchmark, it will be possible to compare the performance of different interest rate rules to make a ranking among them (section 1.6).

1.5 Optimal monetary policy with commitment

In this section, the fully optimal monetary policy under commitment is computed following Clarida, Galí and Gertler (1999) and Giannoni and Woodford (2002).

The system of equations fully characterizing the model (see appendix A.3) can be reduced to the following equations:

$$\alpha(x_t + a_t - y_t^*) = \alpha(x_{t-1} + a_{t-1} - y_{t-1}^*) + \pi_t - \pi_{H,t} \quad (1.44)$$

$$\pi_{w,t} = w_t + \pi_t - w_{t-1} \quad (1.45)$$

$$\pi_{w,t} = \beta E_t \pi_{w,t+1} - \lambda_w \left[w_t - \alpha y_t^* - (1-\alpha)a_t - (1+\varphi-\alpha)(x_t + \frac{\log(1-\alpha)}{1+\varphi})\right] \quad (1.46)$$

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda \alpha x_t + \lambda \left[w_t - \alpha y_t^* - (1-\alpha) a_t - (1+\varphi-\alpha) \frac{\log(1-\alpha)}{1+\varphi} \right] \quad (1.47)$$

$$y_{t+1}^* = \rho_y y_t^* + \varepsilon_{y,t}. \quad (1.48)$$

$$a_{t+1} = \rho_a a_t + \varepsilon_{A,t}. \quad (1.49)$$

With the inclusion of a monetary policy rule, equations (1.44), (1.45), (1.46) and (1.47) define the variables x_t, $\pi_{H,t}$, $\pi_{w,t}$, π_t and w_t, while the last two equations define the law of motion of the two exogenous shocks.

To compute the optimal monetary policy under commitment the central bank has to choose $\{x_t, \pi_{H,t}, \pi_{w,t}, \pi_t, w_t\}_{t=0}^{\infty}$ in order to maximize[9]:

$$W = -\frac{1-\alpha}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[(1+\varphi) x_t^2 + \frac{\theta_p}{\lambda} \pi_{H,t}^2 + \frac{\theta_w}{\lambda_w} \pi_{w,t}^2 \right] \quad (1.50)$$

subject to the sequence of constraints defined by equations (1.44), (1.45), (1.46) and (1.47)[10].

The FOCs of this problem are ($\Phi_{i,t}$ is the Lagrange multiplier associated to the constraint i):

- x_t :

$$-(1-\alpha)(1+\varphi) x_t - \alpha \Phi_{1,t} + \beta \alpha E_t \Phi_{1,t+1} + \alpha \lambda \Phi_{4,t} + \lambda_w (1+\varphi-\alpha) \Phi_{3,t} = 0 \quad (1.51)$$

[9] See appendix A.2 for the derivation of (1.50)

[10] Giannoni and Woodford (2002) do the optimization including also the IS equation among the constraints and maximizing also with respect to the interest rate. Following Clarida et al. (1999) it is possible to divide the problem in two steps. The first is to maximize the welfare with respect to $\{x_t, \pi_{H,t}, \pi_{w,t}, \pi_t, w_t\}_{t=0}^{\infty}$ without considering the IS. The second step, once obtained the optimal responses of those variables to the exogenous shocks, is to use the IS in order to see how the interest rate has to be set under optimal monetary policy.

- $\pi_{H,t}$:

$$-(1-\alpha)\frac{\theta_p}{\lambda}\pi_{H,t} - \Phi_{1,t} - \Phi_{4,t} + \Phi_{4,t-1} = 0 \tag{1.52}$$

- $\pi_{w,t}$:

$$-(1-\alpha)\frac{\theta_w}{\lambda_w}\pi_{w,t} - \Phi_{2,t} - \Phi_{3,t} + \Phi_{3,t-1} = 0 \tag{1.53}$$

- π_t :

$$\Phi_{1,t} + \Phi_{2,t} = 0 \tag{1.54}$$

- w_t :

$$\Phi_{2,t} - \beta E_t \Phi_{2,t+1} - \Phi_{3,t}\lambda_w + \lambda \Phi_{4,t} = 0 \tag{1.55}$$

Equations (1.51)-(1.55) plus the constraints (1.44)-(1.47) fully characterize the behaviour of the economy under optimal monetary policy. Using Uhlig's toolkit[11] it is possible to solve the system of equations and to study the behavior of the variables under optimal monetary policy. In the next section several simple interest rate rules are considered and their performance is evaluated using the optimal monetary policy as benchmark.

1.6 Evaluation of different policy rules

Now we can go back to the original question i.e., assuming that the monetary authority follows a simple rule, once wage rigidity is introduced in a small open economy, is it better to choose domestic inflation as target variable, or is it preferable to target at CPI inflation? To answer this question the performance of several rules will be compared.

In the choice of possible targets for monetary policy, we disregard the output gap, that cannot be considered a feasible target since it is not clear how to estimate the

[11] The model has been simulated using the Matlab program developed by Harald Uhlig. See Uhlig (1995).

natural level of output. We will therefore concentrate on the three inflation variables and consider the following interest rate rules:

$$\begin{aligned} r_t &= \rho + \phi_p \pi_t \\ r_t &= \rho + \phi_{p,H} \pi_{H,t} \\ r_t &= \rho + \phi_w \pi_{w,t} \end{aligned} \tag{1.56}$$

Instead of imposing *a priori* given coefficients for ϕ_p, $\phi_{p,H}$ and ϕ_w, we chose the values that minimize the welfare loss over a given grid of parameters, in order to give to each rule the best chances to perform well. In particular, we use a grid from 1 to 10 with intervals of 0.25. When the rule is attaining the lowest welfare loss in correspondence of $\phi = 10$, we allow this coefficient to take the value of 100 to check whether strict targeting of the corresponding inflation variable is a better option. After presenting the results under a baseline calibration, robustness checks for relevant parameters will be discussed.

1.6.1 Baseline calibration

The baseline calibration coincides with the one used by Galí and Monacelli (2005).

Preferences The relative risk aversion coefficient σ is set to 1 because the welfare function as been derived under this simplifying assumption. $\varphi = 3$, i.e. the labour supply elasticity is set equal to $\frac{1}{3}$. The discount factor is $\beta = 0.99$ which implies a riskless annual return in steady state of 4%.

Goods and Labour Markets The elasticity of substitution between different workers and between different goods are $\theta_p = \theta_w = 6$ implying a mark-up of $\mu = 1.2$ in both goods and labour markets in steady state. The average contract duration is four quarters, i.e. $\xi_p = \xi_w = 0.75$.

Open Economy The elasticity of substitution between home and foreign produced goods η is set equal to 1 because this is the assumption under which the welfare function has been derived. $\alpha = 0.4$ and matches the import/GDP ratio for Canada.

Exogenous Shocks The productivity shock follows an AR(1) process with $\rho_a = 0.66$. The exogenous shock to productivity is an i.i.d with zero mean and standard deviation $\sigma_a = 0.0071$. Galí and Monacelli (2005) computed those numbers using the GDP of Canada as proxy for the output of a small open economy. As proxy for the world output they use the USA GDP therefore, fitting an $AR(1)$ process on the (log) GDP for USA they estimate $\rho_y = 0.86$ and $\sigma_y = 0.0078$. The correlation between the two exogenous shocks is $corr_{a,y} = 0.3$.

1.6.2 Performance of different monetary policy rules

Table 1 reports the welfare losses associated with each interest rate rule[12]. Under the baseline calibration the rule performing best is the one targeting wage inflation. But, what is more important, domestic inflation targeting delivers welfare losses considerably higher then CPI inflation targeting. The ability of a CPI inflation targeting rule to outperform a domestic inflation targeting rule is particularly interesting given that the volatility of CPI inflation does not enter into the loss function. The intuition for this result is simple. As explained previously, because of sticky wages, fluctuations in CPI inflation translate into undesired movements of the wage mark-up acting as an endogenous cost push shock in the economy. Reducing the volatility of CPI inflation reduces such cost push shock and therefore, reduces the trade off faced by the monetary authority. For this reason, it makes it easier to stabilize wage inflation, domestic inflation and output gap. Indeed, from table 1 it is clear that the rule targeting CPI

[12] The welfare losses are measured as percentage units of steady state consumption and are expressed in deviation from the loss under optimal monetary policy.

inflation delivers much better results in terms of reducing the volatility of wage inflation and output gap than the rule targeting domestic inflation and this is why the associated welfare losses are lower.

Therefore, the presence of wage rigidity rationalizes CPI inflation targeting in contrast with the previous literature advocating for domestic inflation targeting.

Of course, those results have been derived under a baseline calibration. Even though the calibration used is pretty standard, it is interesting to study how the relative performance of the rules is affected by some crucial parameters. In the next section a comparison among the rules under different calibrations is presented.

Table 1.1: **Welfare cost of deviation from optimal policy and standard deviations associated to each policy rule.** *Welfare losses are in percentage units of steady state consumption. Standard deviations are also expressed in %. The coefficients of the policy rule minimizing the welfare losses are also reported. A coefficient of 100 stands for strict inflation targeting.*

	Optimal MP	Interest Rate π	Interest Rate π_H	Interest Rate π_w
Welfare Losses	0.0025	$\phi_p = 5.25$ 0.0241	$\phi_{p,H} = 7.05$ 0.0606	$\phi_w = 100$ 0.0002
$\sigma(\pi)$	0.3456	0.0634	0.1604	0.3291
$\sigma(\pi_H)$	0.1037	0.1047	0.0757	0.1047
$\sigma(\pi_w)$	0.0070	0.0542	0.0893	0
$\sigma(x)$	0.0480	1.0228	1.5843	0.1842

1.6.3 Main robustness checks

The parameters over which a robustness check is performed are: the degree of wage stickiness ξ_w; the inverse of the labour supply elasticity φ; the elasticity of substitution between different types of labour θ_w; the elasticity of substitution between different goods θ_p. In order to understand the role played by each component, only one of the parameters is changed in each experiment while the others are kept at their baseline calibration.

Wage stickiness The level of wage rigidity in the economy is probably the most crucial parameter given that, as shown by Galí and Monacelli (2005), when there is no wage rigidity in the economy, the optimal monetary policy coincides with strict domestic inflation targeting and a simple rule targeting domestic inflation outperforms the one targeting CPI inflation. The first check is therefore to see which level of wage rigidity is needed to invert this result.

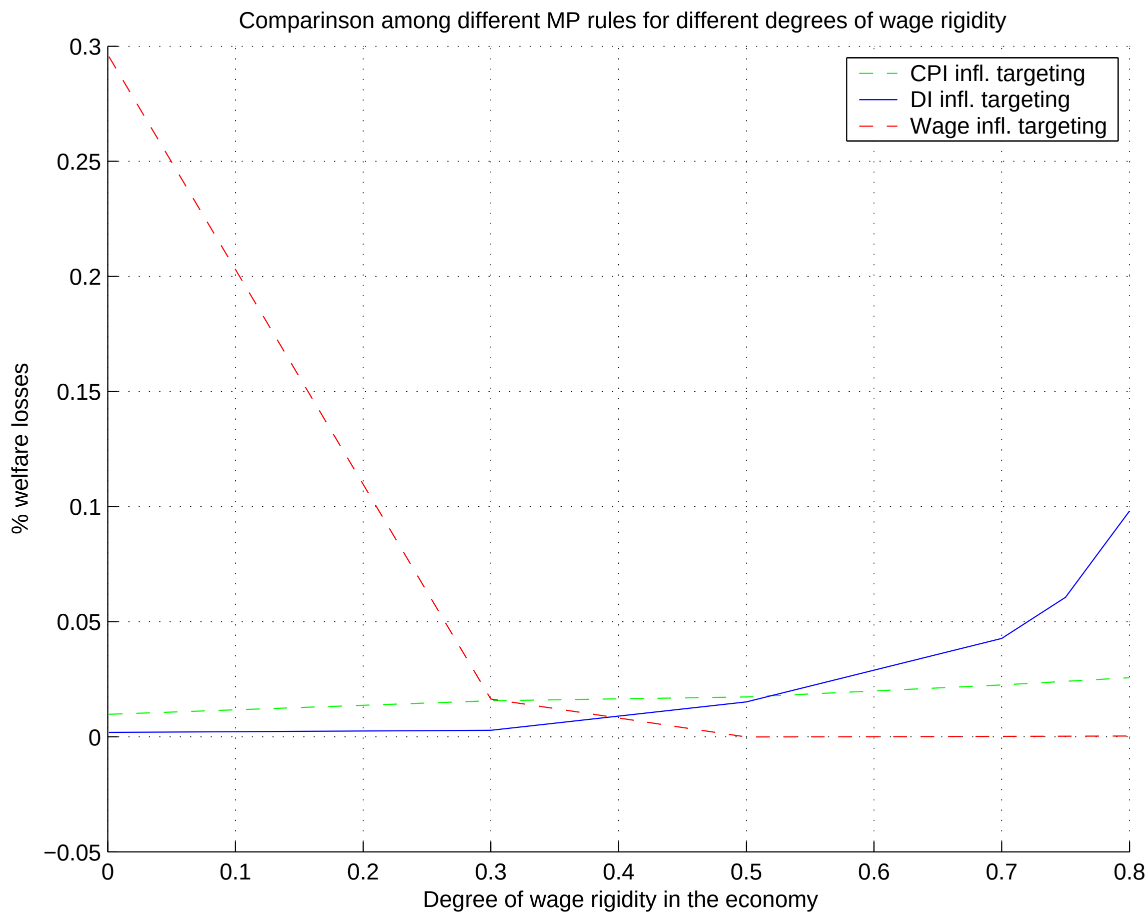

Figure 1.1: Wage Stickiness

From picture 1.1 we can notice that, while the performance of the rules targeting wage inflation and domestic inflation crucially depends on the level of wage rigidity in the economy, this is not the case for the rule targeting at CPI inflation. Indeed, the wage inflation targeting rule performs really bad when there is no wage stickiness and is overall the worst rule for levels of wage rigidity below 0.3 while it becomes the best rule for levels of wage rigidity above 0.4. The opposite is true for the domestic inflation targeting rule which coincides with the optimal monetary policy when $\xi_w = 0$ and is the best rule for low levels of wage rigidity. The threshold value for the two price inflation targeting rules is $\xi_w = 0.5$. Whenever the level of wage rigidity is above such value, the rule targeting CPI inflation outperforms the one targeting domestic inflation. Recall that the level of price rigidity under which the experiment is run is the baseline value $\xi_p = 0.75$ i.e, the CPI inflation targeting rule has to be preferred to the domestic inflation targeting rule even when the level of price rigidity in the economy is higher then the degree of wage rigidity.

Labour supply elasticity An even more crucial parameter is the inverse of the labour supply elasticity φ. Indeed, while it is very standard to assume $\xi_w = 0.75$, in the literature different values for φ are used. The baseline calibration is 3. In figure 1.2 different welfare losses for values of φ ranging from 1 to 10 are reported. Independently on the level of labour supply elasticity, domestic inflation targeting is always worst than CPI inflation targeting. Reducing the elasticity amplifies the distance between the two rules. This is reasonable given that a lower elasticity (i.e a higher φ) implies a bigger penalization of both output gap and wage inflation variability and we saw under the baseline calibration that domestic inflation targeting fails to contain the variability of those two variables.

Wage markup Another parameter for which different calibrations can be found in the literature is the elasticity of substitution between different labour types, θ_w. In the baseline calibration it has been set to 6, implying a wage markup of 1.2. In figure 1.3 it is allowed to vary between 4 and 12. As for the labour elasticity, changing this

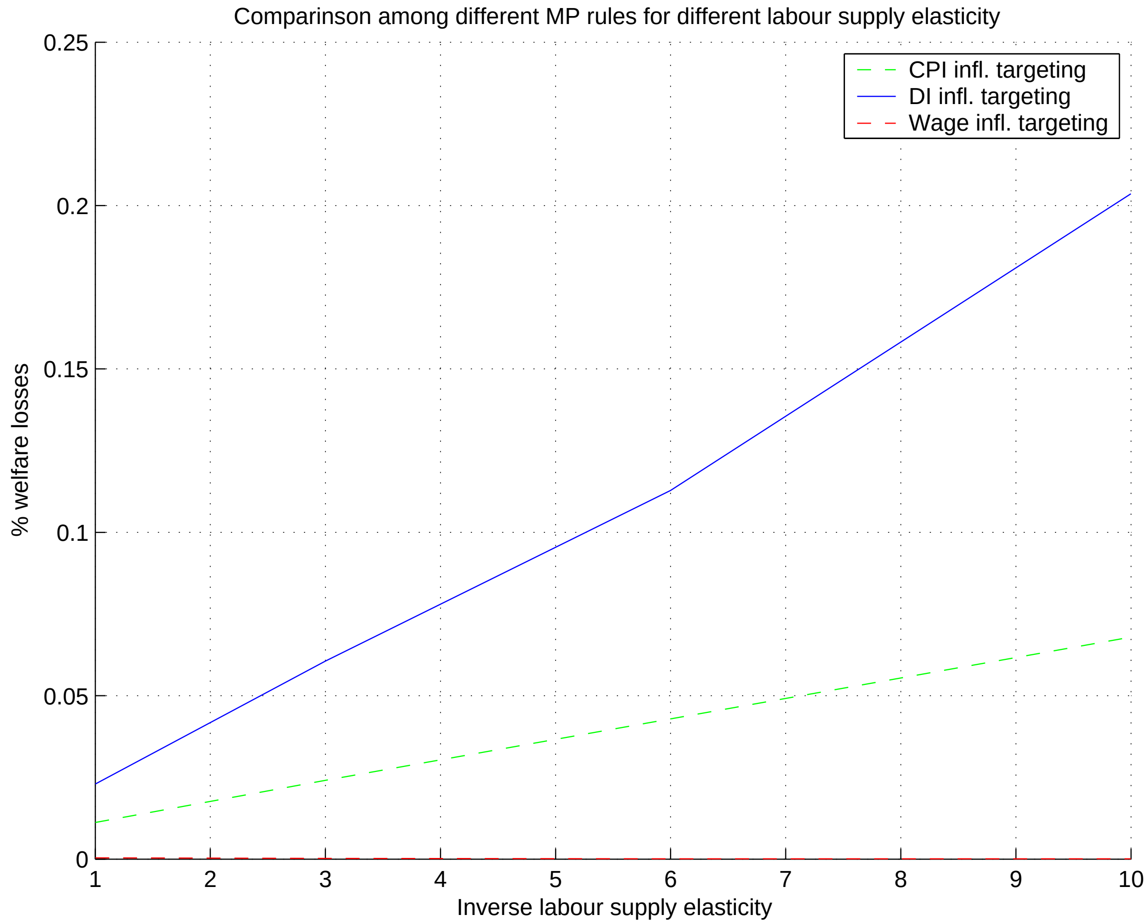

Figure 1.2: Inverse labour elasticity

parameter does not alter the ranking of the rules. However, for values of θ_w above 6 the performance of the domestic inflation targeting rule progressively worsen. This is again due to the fact that a high elasticity of substitution implies a high weight on the loss function to wage volatility.

1.6.4 Other checks

We have done other robustness checks for which the pictures are not reported for brevity.

Allowing θ_p to vary between 4 and 12 changes the weight of domestic inflation

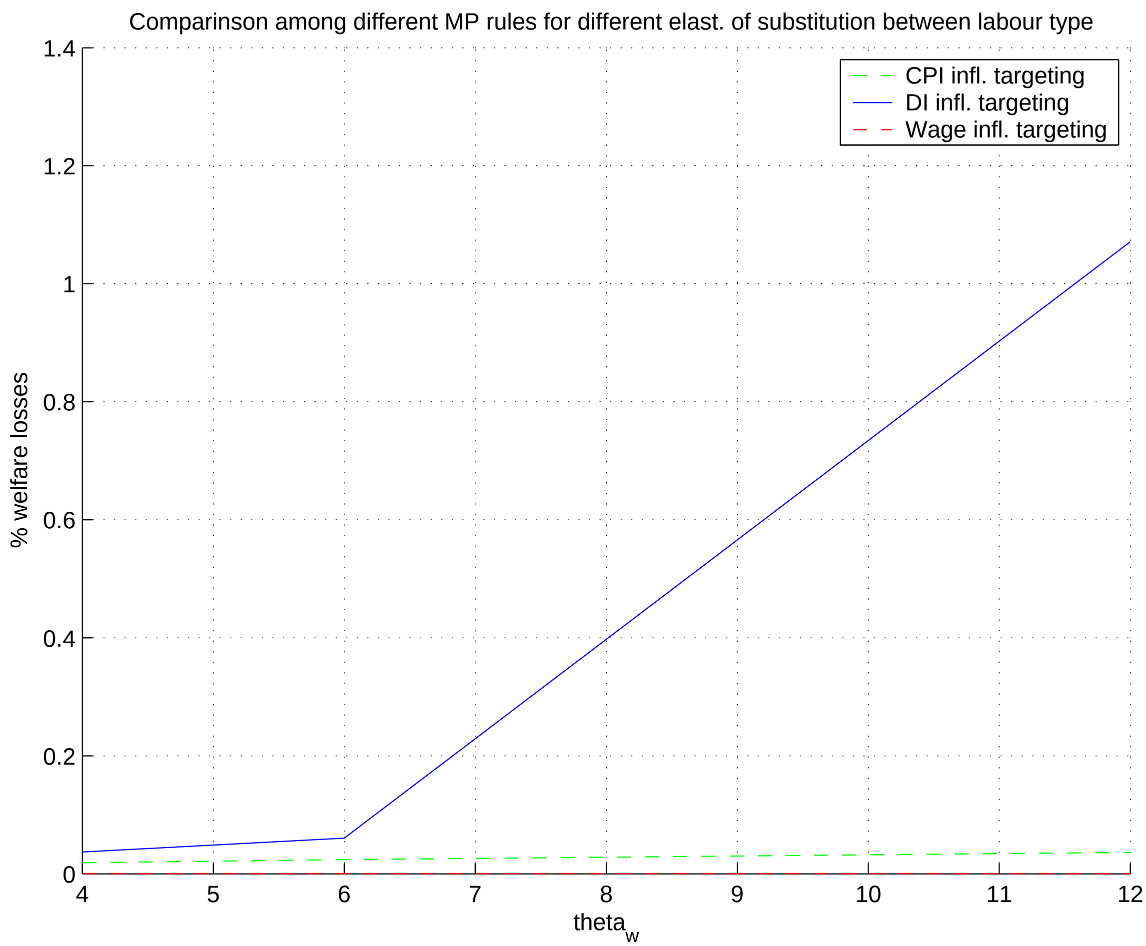

Figure 1.3: Wage Mark-up

volatility in the loss function but, given that the rules all deliver very similar volatility for this variable, changing this parameter does not change the results at all.

Decreasing the degree of price rigidity clearly worsen the performance of domestic inflation targeting and the same happens if we increase the autocorrelation coefficient for the technological process ρ_a.

1.7 Conclusions

The question addressed in the paper is whether the introduction of wage rigidities in a small open economy model is enough to rationalize the observed behaviour of many central banks that are targeting CPI inflation. As in the closed economy case, once both price and wage rigidities are present, it is no longer possible to reach the flexible price allocation because the central bank cannot simultaneously stabilize price inflation, wage inflation and the output gap. Given this, an interesting question was if it were still true that targeting domestic inflation is the best that a central bank can do. To this purpose, we derived the loss function from a second order approximation of the utility of the representative consumer. After deriving the optimal monetary policy under commitment, we then simulated the model under different simple interest rate rules, in order to make a ranking among them, using the optimal monetary policy as a benchmark. The main result is that, under the baseline calibration a rule targeting domestic inflation delivers considerably larger welfare losses than a rule targeting CPI inflation. Several robustness checks have been provided, confirming all the same results. Therefore we can conclude that wage stickiness provides a rational for CPI inflation targeting.

Chapter 2

Labor Market Institutions and Inflation Volatility in the Euro Area

[1]

2.1 Introduction

Inflation differentials are still pronounced among euro area countries despite the existence, for many years, of a common currency, a single market for products, capital and labor (though with low labor mobility) and tightly harmonized fiscal policies. Why is it so? Research to date has concentrated on differentials in inflation levels, explaining their size and persistence on the basis of convergence mechanisms such as the "Balassa Samuelson", or asymmetric national shocks (in aggregate demand, or supply, or in the degree of exposure to area-wide external shocks), whose effect are typically exacerbated by high inflation persistence[2]. Here we look instead at inflation

[1] Joint with Ester Faia.

[2] See European Central Bank Inflation report Eur (2003) for a non-technical survey and Honohan and Lane (2003) and Angeloni and Ehrmann (2007), and the references therein, for some interpretations of the evidence.

volatility differentials and study their link with labor market institutions – specifically, the replacement rate which is the ratio between unemployment benefit and wage.

We think that the properties of euro area inflation we document and the explanation we offer may be deeper and more long-lasting than those studied by other authors. While convergence phenomena are by nature transient, and inflation persistence in the eurozone can be expected to decline as a result of product market reforms and enhanced central bank credibility, labor market structures (unemployment insurance in particular) are deeply entrenched in national preferences[3] and hence should be expected to vary little over time. Linking them to inflation volatility differentials hence means pointing at features of inflation asymmetry in the EMU that will be very difficult to remove, even at much higher levels of economic and financial integration than that prevailing at present.

Labor market characteristics influence the dynamics of real wages and of the marginal cost of firms, which, in the standard New-Keynesian model, are a main driver of inflation. Hence it seems natural to assess the quantitative relevance of such institutions in determining differentials in inflation behavior. Specifically, the intuition behind our reasoning is the following. Consider e.g. a shock that reduces real wages in a given country in EMU. If the replacement rate is lower, workers face a worse outside option and therefore are willing to accept a bigger reduction in wage in order to keep their jobs. Assuming little or no labor mobility, in the country with low replacement rate we should observe in equilibrium a higher reduction in real wage, marginal costs as well as inflation, since inflation is linked to marginal costs via the Phillips curve. In general, the volatility of real wages, marginal costs and inflation is inversely related to the replacement rate. The shape of the relation depends not only

[3]See Sapir (2006).

on labor market characteristics but on the whole shock and propagation mechanisms, including (since EMU countries are highly integrated in trade and capital markets) the cross-country spillovers.

Our analysis proceeds as follows. We first document the negative empirical relation between volatilities of de-trended real wages, marginal costs and inflation and replacement rates[4] during the EMU period. Secondly, we build a DSGE model with two countries sharing the same currency, characterized by matching frictions and wage rigidity in the labor market[5], monopolistic competition and adjustment cost on pricing. The two-country model accounts for the rich structure of propagation mechanisms and international spillovers existing in a monetary union. We use this laboratory economy, calibrated on the euro area, to analyze the effect of shocks under different values of the replacement rates, and find that the model also gives rise to a negative relation. Finally, we match the model results with the empirical ones, and find that the model replicates well the relations found in the data.

In section 2.2 we present our empirical stylized facts; in section 2.3 we present the model and its calibration, in section 2.4 we show the model results and we match them with the data. Section 2.5 concludes.

2.2 Stylized Facts

Table (2.1) shows averages over 1998 to 2004 of replacement rates for a series of euro area countries. Data are taken from Nickell and Nunziata (2007). As a measure of unemployment insurance coverage they use the benefit replacement rate (BBR, benefit as a ratio to average earnings before taxes) provided by OECD, which is a

[4] As calculated by Nickell and Nunziata (2007).

[5] The tradition of introducing matching frictions in DSGE closed economy model is well established. See Merz (1995), Andolfatto (1996), Cooley and Quadrini (1999), Shimer (2005), Hall (2005) and Krause and Lubik (2005) among many others.

measure of the monetary loss incurred by the worker when moving from the employed to the unemployed status. To proxy a dynamic concept of unemployment insurance benefit, Nickell and Nunziata calculate a weighted average of the BRR over the first 5 years of unemployment; for example, the first entry in the table means that an Austrian worker in the first 5 years of unemployment earns on average 89 percent of her last wage when employed.

Several features of the data are worth noting. First, there is considerable cross-country variation, from a minimum of 0.39 to a maximum of 0.89; this seems a large enough span to have an observable macroeconomic impact. It is worth noticing that we observe much cross-country variation but little time variation[6], suggesting that indeed the BRR incorporates deeply entrenched features of the national systems. In the literature this parameter is often use as a catch-all measure of unemployment insurance, and is assumed to be a key determinant in the worker's decision to keep a job. A further advantage of this measure is that it is easily comparable across countries.

In our analysis we consider the euro area countries during the period 1998Q1-2004Q4. 1998 is included in the sample because during most of that year exchange rates were virtually constant and EMU was expected with certainty to start at the beginning of the following year (in fact, the ECB as created in mid-1998, not in 1999 as often assumed). Among the original EMU members, we exclude Luxembourg because there are no data on replacement rates, hence making a total of 10 countries[7].

In figure 2.1 (panels a, b and c) we plot on the vertical axis the volatilities of wage, of unit labor costs and inflation, all measured relative to the volatility of output in

[6]Despite the fact that some countries have undertaken reforms in the last decade there is still a considerable cross-country variation. In comparing replacement rates data across different periods (pre and post EMU) we came across two observations. First, all EMU countries have undertaken reforms that increased the size and duration of the unemployment benefits. Secondly, despite those reforms the relative ranking across countries remained the same as there was still little convergence.

[7]For the real wage, also Portugal is missing.

the corresponding countries[8], and on the horizontal axis the replacement rates[9].

Inflation rates are measured by the GDP deflator. As measure of real wages we use the hourly earnings divided by the CPI and as a measure of marginal cost the unit labor cost. Data are taken from OECD. The standard deviations have been computed on Hodrick-Prescott filtered series. In all three charts we drew two interpolating lines, a linear and an exponential one. All lines shows a negative relation, and the exponential is convex relative to the origin. The evidence of a negative and convex relation seems quite clear and robust across the three measures of volatility. Overall the relations are statistically significant apart from the one on marginal cost[10].

Figure 2.2 (panels a, b and c) shows the same variables, but this time as ratios between pairs of countries[11]. Hence each dot shows, for a given pair of countries, the ratio between the standard deviations (relative to that of output) of real wages, marginal costs and inflation, respectively, plotted against the corresponding ratios of the replacement rates. We show these transformations of the original data because this is the appropriate way to match the model results with the data, as explained below. The negative relation, linear and non-linear, is again clear and statistically significant.

[8] We divided by the volatility of output to have a standardized measure.

[9] Replacement rates are averages over the period 1998-2004.

[10] It is a well known problem in the literature that measures of marginal costs are often associated with low statistical significance. The reason for this is that marginal costs are approximated in the data by measures of average costs. Such an approximation is valid under the assumption of Cobb-Douglas production function. However this assumption might easily fail to hold.

[11] Using differences instead of ratios would not materially change the results.

2.3 A Model for A Currency Area with Labor Market Frictions

There are two countries of equal size. Each economy is populated by households who consume different varieties of domestically produced and imported goods, save and work. Households save in both domestic and internationally traded bonds. Each agent can be either employed or unemployed. In the first case he receives a wage that is determined according to a Nash bargaining, in the second case he receives an unemployment benefit. The labor market is characterized by matching frictions and endogenous job separation. The production sector acts as a monopolistic competitive sector which produces a differentiated good using capital and labor as inputs and faces adjustment costs a' la Rotemberg (1982).

2.3.1 Households in the Domestic and Foreign Country

Let's denote[12] by $c_t \equiv [(1-\gamma)^{\frac{1}{\eta}} c_{h,t}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} c_{f,t}^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}}$ a composite consumption index of domestic and imported bundles of goods, where γ is the balanced-trade steady state share of imported goods (i.e., an inverse measure of home bias in consumption preferences), and $\eta > 0$ is the elasticity of substitution between domestic and foreign goods. Optimal allocation of expenditure between domestic and foreign bundles yields:

$$c_{h,t} = (1-\gamma)\left(\frac{p_{h,t}}{p_t}\right)^{-\eta} c_t;\; c_{f,t} = \gamma\left(\frac{p_{f,t}}{p_t}\right)^{-\eta} c_t \tag{2.1}$$

Each bundle is then composed of imperfectly substitutable varieties (with elasticity of substitution $\varepsilon > 1$).There is continuum of agents who maximize the expected lifetime utility.

[12]Let $s^t = \{s_0, ...s_t\}$ denote the history of events up to date t, where s_t denotes the event realization at date t. The date 0 probability of observing history s^t is given by ρ_t. The initial state s^0 is given so that $\rho_0 = 1$. Henceforth, and for the sake of simplifying the notation, let's define the operator $E_t\{.\} \equiv \sum_{s_{t+1}} \rho(s^{t+1}|s^t)$ as the mathematical expectations over all possible states of nature conditional on history s^t.

$$E_t \left\{ \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\sigma}}{1-\sigma} \right\} \tag{2.2}$$

where c denotes aggregate consumption in final goods. Households supply labor hours inelastically h (which we normalize to 1). Total real labor income is given by w_t and is specified below. Unemployed households members, u_t, receive an unemployment benefit, b. The contract signed between the worker and the firm specifies the wage and is obtained through a Nash bargaining process. In order to finance consumption at time t each agent also invests in non-state contingent nominal bonds b_t which pay a gross nominal interest rate $(1 + r_t^n)$ one period later and in non-state contingent nominal bonds which are internationally traded, b_t^*, and which pay a gross nominal interest rate, $(1 + r_t^{n,f})$, one period later. As in Andolfatto (1996) and Merz (1995) it is assumed that workers can insure themselves against earning uncertainty and unemployment. For this reason the wage earnings have to be interpreted as net of insurance costs. Finally agents receive profits from the monopolistic sector which they own, Θ_t, and pay lump sum taxes, τ_t. The sequence of budget constraints in terms of domestic CPI consumption goods reads as follows:

$$c_t + \frac{b_t}{p_t} + e_t^r \frac{b_t^*}{p_t^*} \leq w_t(1-u_t) + bu_t + \frac{\Theta_t}{p_t} - \frac{\tau_t}{p_t} + (1+r_{t-1}^n)\frac{b_{t-1}}{p_t} + (1+r_{t-1}^{n,f}) e_t^r \frac{b_{t-1}^*}{p_t^*} \tag{2.3}$$

where e_t^r is the real exchange rate which in the currency area is given by $e_t^r = \frac{p_t^*}{p_t}$.Households choose the set of processes $\{c_t, b_t, b_t^*\}_{t=0}^{\infty}$ taking as given the set of processes $\{p_t,\ w_t,\ r_t^n, r_t^{n,f}\}_{t=0}^{\infty}$ and the initial wealth b_0, b_0^* so as to maximize (2.2) subject to (2.3). The following optimality conditions must hold:

$$c_t^{-\sigma} = \beta(1+r_t^n) E_t \left\{ c_{t+1}^{-\sigma} \frac{p_t}{p_{t+1}} \right\} \tag{2.4}$$

$$c_t^{-\sigma} = \beta(1+r_t^{n,f}) E_t \left\{ c_{t+1}^{-\sigma} \frac{p_t^*}{p_{t+1}^*} \frac{e_{t+1}^r}{e_t^r} \right\} \tag{2.5}$$

$$c_t^{-\sigma} = \lambda_t \tag{2.6}$$

Equation (2.4) is the Euler condition with respect to domestic bonds. Equation (2.5) is the optimality condition with respect to internationally traded bonds. Equations (2.6) is the marginal utility of consumption. Optimality requires that No-Ponzi condition on wealth is also satisfied.

Arbitrage condition and accumulation of assets. Due to imperfect capital mobility and/or in order to capture the existence of intermediation costs in foreign asset markets workers pay a spread between the interest rate on the foreign currency portfolio and the interest rate of the foreign country. This spread is proportional to the (real) value of the country's net foreign asset position:

$$\frac{(1 + r_t^{n,f})}{(1 + r_t^{n,*})} = \zeta \left(e_t^r \frac{b_t^*}{p_t^*} \right) \tag{2.7}$$

where $\zeta > 0$[13], $\zeta' > 0$. In addition we assume that the initial distribution of wealth between the two countries is symmetric.

Workers in the Foreign Region. We assume throughout that all goods are traded, that both countries face the same composition of consumption bundle and that the *law of one price* holds. This implies that $p_{h,t} = p_{h,t}^*, p_{f,t} = p_{f,t}^*$. Under the currency union assumption the nominal exchange rate is equal one. Foreign workers face an allocation of expenditure and wealth similar to the one of workers in the domestic region except for the fact that they do not pay an additional spread for investing in the international portfolio. The efficiency condition for bonds' holdings

[13] As shown in Schmitt-Grohé and Uribe (2003) and Benigno (2001) this assumption is needed in order to maintain the stationarity in the model. Schmitt-Grohé and Uribe (2003) also show that adding this spread - i.e. whose size has been shown negligible in Lane and Milesi-Ferreti (2003) - does not change significantly the behavior of the economy as compared to the one observed under the complete asset market assumption or under the introduction of other inducing stationarity elements - see Mendoza (1991), Senhadji (2003), Ghironi (2006). The last observation applies in our case as well. We have decided to employ the incomplete structure with intermediation costs for international markets since this suits better with the structure of the financial markets used in Andolfatto (1996) which we use for workers' insurance.

will read as follow:

$$(c_t^*)^{-\sigma} = \beta(1 + r_t^{n,*})E_t \left\{ (c_{t+1}^*)^{-\sigma} \frac{p_t^*}{p_{t+1}^*} \right\} \tag{2.8}$$

All other optimality conditions are like in the home region. After substituting equation (2.7) into equation (2.5) and after merging with (2.4) we obtain the following relation:

$$E_t \left\{ \frac{\lambda_{t+1}^*}{\lambda_t^*} \right\} = E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \frac{e_{t+1}^r}{e_t^r} \zeta \left(e_t^r \frac{b_t^*}{p_t^*} \right) \right\} \tag{2.9}$$

which states that marginal utilities across countries are equalized up to the spread for the country risk.

2.3.2 The Production Sector In the Domestic and the Foreign Region

The maximization problems which characterize the production sector[14] are symmetric across the two economies. In the next section we show only the ones for the home region. Firms in the production sector sell their output in a monopolistic competitive market and meet workers on a matching market. The labor relations are determined according to a standard Mortensen and Pissarides (1999) framework.

Search and Matching in the Labor Market of the Home Region

The search for a worker involves a fixed cost κ and the probability of finding a worker depends on a constant return to scale matching technology which converts unemployed workers u and vacancies v into matches, m:

$$m(u_t, v_t) = m u_t^{\xi} v_t^{1-\xi} \tag{2.10}$$

[14] We follow Krause and Lubik (2005).

where $v_t = \int_0^1 v_{i,t} di$. Defining labor market tightness as $\theta_t \equiv \frac{v_t}{u_t}$, the firm meets unemployed workers at rate $q(\theta) = \frac{m(u_t, v_t)}{v_t} = m\theta_t^{-\xi}$, while the unemployed workers meet vacancies at rate $\theta_t q(\theta_t) = m\theta_t^{1-\xi}$. If the search process is successful, the firm in the monopolistic good sector operates the following technology:

$$y_{i,t} = z_t n_{i,t} \int_{\tilde{a}_{i,t}}^{\infty} a \frac{f(a)}{1 - F(\tilde{a}_{i,t})} da = z_t n_{i,t} H(\tilde{a}_{i,t}) \tag{2.11}$$

where z_t is the aggregate productivity shock which follows a first order autoregressive process, $n_{i,t}$ is the number of workers hired by each firm, and $a_{i,t}$ is an idiosyncratic shock to firms which is assumed to be identically and independently distributed across firms and times with cumulative distribution function $F : [0, \infty] \rightarrow [0, 1]$. It is assumed that the idiosyncratic shock is observed before the firm starts production. The firm will endogenously discontinue the match if the realized shock, $a_{i,t}$, is below a certain cut-off value, $\tilde{a}_{i,t}$. The threshold for endogenous separation is determined as a function of the state of the economy using firms' optimality conditions.

Matches are destroyed at varying rate $\rho(\tilde{a}_{i,t})$ given by the following expression:

$$\rho(\tilde{a}_{i,t}) = \rho^x + \rho^n(\tilde{a}_{i,t})(1 - \rho^x) \tag{2.12}$$

where ρ^x is the exogenous break-up rate and $\rho^n(\tilde{a}_{i,t}) = F(\tilde{a}_{i,t})$ is the endogenous break-up rate.

We are now in the position to determine the law of motion for the workers employed and the ones seeking for a job. Labor force is normalized to unity. The number of employed people at time t in each firm i is given by the number of employed people at time $t - 1$ plus the flow of new matches concluded in period $t - 1$ who did not discontinue the match:

$$n_{i,t} = (1 - \rho(\tilde{a}_{i,t}))(n_{i,t-1} + v_{i,t-1} q(\theta_{t-1})) \tag{2.13}$$

Finally we define the gross job destruction and job creation rates as follows:

$$jd_t = \rho(\tilde{a}_{i,t}) - \rho^x \tag{2.14}$$

$$jc_t = \frac{(1-\rho(\tilde{a}_{i,t}))v_{t-1}q(\theta_{t-1})}{n_{t-1}} - \rho^x \tag{2.15}$$

Monopolistic Firms

Firms in the monopolistic sector (of the home region) use labor to produce different varieties of consumption good and face a quadratic cost of adjusting prices. Wages are determined through the bargaining problem analyzed in the next section. Here we develop the dynamic optimization decision of firms choosing prices, $p^i_{h,t}$, number of employees, $n_{i,t}$, number of vacancies, $v_{i,t}$, and the endogenous separation threshold, $\tilde{a}_{i,t}$, to maximize the discounted value of future profits and taking as given the wage schedule. Let's denote the total real wage bill of firm i (measured in CPI goods) by:

$$W_{i,t} = n_{i,t} \int_{\tilde{a}_{i,t}}^{\infty} w(a) \frac{f(a)}{1-F(\tilde{a}_{i,t})} da \tag{2.16}$$

where $w(a)$ denotes the fact that the bargained wage might depend on idiosyncratic shock and other time varying factors. Given the definition of the terms of trade, $s_t \equiv \frac{p_{f,t}}{p_{h,t}}$, let's define:

$$\phi_t \equiv \frac{p_t}{p_{h,t}} = [(1-\gamma) + \gamma s_t^{1-\eta}]^{\frac{1}{1-\eta}} \tag{2.17}$$

The representative firm in the domestic region chooses $\left\{p^i_{h,t}, n_{i,t}, v_{i,t}, \tilde{a}_{i,t}\right\}$ to solve the following maximization problem (in real terms):

$$Max\Pi_{i,t} = E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left\{ \frac{p^i_{h,t}}{p_{h,t}} y^i_t - \phi_t W_{i,t} - \kappa v_{i,t} - \frac{\psi}{2} \left(\frac{p^i_{h,t}}{p^i_{h,t-1}} - 1 \right)^2 y^i_t \right\} \tag{2.18}$$

subject to

$$\text{s.to:} \qquad y^i_t = \left(\frac{p^i_{h,t}}{p_{h,t}} \right)^{-\epsilon} (c_{w,t}) = z_t n_{i,t} H(\tilde{a}_{i,t}) \tag{2.19}$$

$$\text{and: } n_{i,t} = (1 - \rho(\tilde{a}_{i,t}))(n_{i,t-1} + v_{i,t-1}q(\theta_{t-1})) \tag{2.20}$$

where $c_{w,t} = c_{h,t} + c^*_{h,t}$, where $\frac{\psi}{2}\left(\frac{p^i_{h,t}}{p^i_{h,t-1}} - 1\right)^2 y^i_t$ represents the cost of adjusting prices and ψ can be thought as the sluggishness in the price adjustment process and κ as the cost of posting vacancies. Let's define mc_t, the lagrange multiplier on constraint (2.19), as the marginal cost of firms and μ_t, the lagrange multiplier on constraint (2.20), as the marginal value of one worker. Since all firms will chose in equilibrium the same price and allocation we can now assume symmetry and drop the index i. First order conditions for the above problem read as follows:

- n_t :

$$\mu_t = mc_t z_t H(\tilde{a}_t) - \phi_t \frac{\partial W_t}{\partial n_t} + \beta E_t(\frac{\lambda_{t+1}}{\lambda_t})((1 - \rho(\tilde{a}_{t+1}))\mu_{t+1}) \tag{2.21}$$

- v_t :

$$\frac{\kappa}{q(\theta_t)} = \beta E_t(\frac{\lambda_{t+1}}{\lambda_t})((1 - \rho(\tilde{a}_{t+1}))\mu_{t+1}) \tag{2.22}$$

- $p_{h,t}$:

$$\frac{c_{w,t}}{y_t}[1 - (1 - mc_t)\varepsilon] - \psi(\pi_{h,t} - 1)\pi_{h,t} + \beta E_t(\frac{\lambda_{t+1}}{\lambda_t})[\psi(\pi_{h,t+1} - 1)\pi_{h,t+1}\frac{y_{t+1}}{y_t}] = 0 \tag{2.23}$$

- $\tilde{a}_t$:

$$\mu_t \rho'(\tilde{a}_t)(n_{t-1} + v_{t-1}q(\theta_{t-1})) + \phi_t \frac{\partial W_t}{\partial \tilde{a}_t} = mc_t z_t n_t H'(\tilde{a}_t) \tag{2.24}$$

Merging equations (2.21) and (2.22) gives the marginal value of an extra worker, μ_t, which is obtained by trading-off the cost of maintaining the match with an existing worker with the cost of posting a new vacancy:

$$\mu_t = mc_t z_t H(\tilde{a}_t) - \phi_t \frac{\partial W_t}{\partial n_t} + \frac{\kappa}{q(\theta_t)} \tag{2.25}$$

After substituting the marginal value of an extra worker, μ_t,into the optimality condition, (2.24), using the constraint which describes the evolution of employment, (2.20), and simplifying we obtain a relation between the threshold value and the real wage schedule:

$$mc_t z_t \tilde{a}_t - w(\tilde{a}_t)\phi_t + \frac{\kappa}{q(\theta_t)} = 0 \tag{2.26}$$

Bellman Equations, Wage Setting and Nash Bargaining

The wage schedule is obtained through the solution to an individual Nash bargaining process. To solve for it we need first to derive the marginal values of a match for both, firms and workers. Those values will indeed enter the sharing rule of the bargaining process. Let's denote by $V_t^J(a_t)$ the marginal discounted value of a match for a domestic firm measured in terms of domestic prices:

$$V_t^J(a_t) = mc_t z_t a_t - \phi_t w(a_t) + E_t\{(\beta\frac{\lambda_{t+1}}{\lambda_t})[(1-\rho(\tilde{a}_{t+1}))\int_{\tilde{a}_{t+1}}^{\infty} V_{t+1}^J(a_{t+1})\frac{f(a)}{1-F(\tilde{a}_{t+1})}da]\} \tag{2.27}$$

The marginal value of a match depends on real revenues minus the real wage plus the discounted continuation value. With probability $(1-\rho(\tilde{a}_{t+1}))$ the job remains filled and earns the expected value and with probability, $\rho(\tilde{a}_{t+1})$, the job is destroyed and has zero value. For each worker, the values of being employed and unemployed are given by V_t^E and V_t^U (expressed in terms of CPI):

$$V_t^E(a_t) = w_t + E_t\{(\beta\frac{\lambda_{t+1}}{\lambda_t})[(1-\rho(\tilde{a}_{t+1}))\int_{\tilde{a}_{t+1}}^{\infty} V_{t+1}^E(a_{t+1})\frac{f(a)}{1-F(\tilde{a}_{t+1})}da + \rho(\tilde{a}_{t+1})V_{t+1}^U]\} \tag{2.28}$$

$$\begin{aligned} V_t^U = {} & b + E_t\{(\beta\frac{\lambda_{t+1}}{\lambda_t})[\theta_t q(\theta_t)(1-\rho(\tilde{a}_{t+1}))\int_{\tilde{a}_{t+1}}^{\infty} V_{t+1}^E(a_{t+1})\frac{f(a)}{1-F(\tilde{a}_{t+1})}da \\ & + (1-\theta_t q(\theta_t)(1-\rho(\tilde{a}_{t+1})))V_{t+1}^U]\} \end{aligned} \tag{2.29}$$

where b denotes real unemployment benefits.

Nash bargaining. Workers and firms are engaged in a Nash bargaining process to determine wages. The standard Nash bargaining problem is given by:

$$\max_{w} \left(\phi_t(V_t^E(a_t) - V_t^U)\right)^{\varsigma} \left(V_t^J(a_t)\right)^{1-\varsigma} \tag{2.30}$$

where ς stands for the bargaining weight of the workers. After substituting the previously defined value functions in the optimal sharing rule it is possible derive the following wage schedule:

$$w_t(a_t) = \varsigma(mc_t z_t a_t + \theta_t \kappa)\frac{1}{\phi_t} + (1-\varsigma)b \tag{2.31}$$

Total real wage is obtained by aggregating across employees: $w_t = \int_{\tilde{a}_t}^{\infty} w(a)\frac{f(a)}{1-F(\tilde{a}_t)}da$. Equation (2.31) shows how the replacement rate affects the real wage which in turn has an impact on the threshold value of the idiosyncratic shock, as shown by equation (2.26), and on the marginal cost. From equation (2.25) indeed we can derive a measure of the marginal cost in our model which reads as follows:

$$mc_t = \frac{1}{z_t H(\tilde{a}_t)}[\phi_t \frac{\partial W_t}{\partial n_t} + \mu_t - \frac{\kappa}{q(\theta_t)}]$$

The first component of this measure is given by the marginal wage bargained divided by the labor productivity. This relation shows that the dynamic of the real wage has an impact on the dynamic of the marginal cost which in turn has an impact on the dynamic of inflation via equation (2.23).

Real wage rigidity. As shown in Shimer (2005), Hall (2005) and Krause and Lubik (2005) introducing real wage rigidity improves the performance of the matching model in terms of the dynamic of labor market variables. We borrow from Hall (2005) and assume a simple form of wage rigidity which serves well our purposes. In particular we assume that the individual real wage is weighted average of the one obtained through the Nash bargaining process and the one obtained as solution to the steady state[15]:

$$w_t(a) = \lambda[\varsigma(mc_t z_t a_t + \theta_t \kappa)\frac{1}{\phi_t} + (1-\varsigma)b] + (1-\lambda)w(a) \tag{2.32}$$

2.3.3 The Monetary Policy Rule in the Currency Area

An active monetary policy sets the short term nominal interest rate by reacting to an average of the inflation levels in the area. This rule rationalizes the behavior of the stability pact signed by euro area countries:

$$r_t^n = \exp(\frac{1-\chi}{\beta})(r_{t-1}^n)^{\chi}((\frac{\pi_t + \pi_t^*}{2})^{b_\pi})^{1-\chi} m_t \tag{2.33}$$

b_π is the weight that the monetary authority puts on the deviation of CPI inflation and is set equal to 1.5. m_t is a temporary monetary policy shock. In addition following Clarida, Galí and Gertler (2000) and Rotemberg and Woodford (1997) we assume that monetary policy applies a certain degree χ of interest rate smoothing. Aside from being consistent with most evidence on monetary policy rules the interest rate smoothing helps to generate more persistent effect of monetary policy shocks.

2.3.4 Equilibrium Conditions

Aggregate output is obtained by aggregating production of individual firms and by subtracting the resources wasted into the search activity:

$$Y_t = n_t z_t \int_{\tilde{a}_t}^{\infty} a \frac{f(a)}{1-F(\tilde{a}_t)} da - \kappa v_t \tag{2.34}$$

After imposing market clearing, aggregating and recalling that $p_{h,t} = p_{h,t}^*$, we can express the resource constraint as:

$$n_t z_t \int_{\tilde{a}_t}^{\infty} a_t \frac{f(a)}{1-F(\tilde{a}_t)} da - \kappa v_t = \left(\frac{p_{h,t}}{p_t}\right)^{-\eta} (1-\gamma)\, c_t + \left(\frac{p_{h,t}}{e_t p_t^*}\right)^{-\eta} \gamma^* c_t^* + \frac{\psi}{2}\left(\frac{p_{h,t}^i}{p_{h,t-1}^i} - 1\right)^2 y_t \tag{2.35}$$

[15]Hall (2005) proves that such a wage rule follows inside the range defined by the bargaining set.

We assume zero total net supply of bonds.

2.3.5 Calibration

Preferences. Time is taken as quarters. We set the discount factor $\beta = 0.99$, so that the annual interest rate is equal to 4 percent. We set the elasticity of substitution between domestic and foreign goods η equal to 1.5 as in Backus, Kehoe and E. (1992). The parameter on consumption in the utility function is set equal to one. This value is compatible with a steady state trade balanced growth path. We set γ to 0.25, a value compatible with data for European countries. Finally we assume that the steady state net asset position is symmetric between the two countries. Following Schmitt-Grohé and Uribe (2003) and consistently with Lane and Milesi-Ferreti (2003) we set the elasticity of the spread on foreign bonds to the net asset position equal to 0.000742.

Production. Following Basu and Fernald (1997) we set the value added mark-up of prices over marginal cost to 0.2. This generates a value for the price elasticity of demand, ε, of 6. We set the cost of adjusting prices $\psi = 100$ to generate a slope of the log-linear Phillips curve equal to 0.10. This is compatible with the estimates by Benigno and López-Salido (2002) for France and Germany. We have also checked our results with different values for ψ and verified that they remain unchanged.

Labor market frictions parameters. The matching technology is a homogenous of degree one function which is characterized by the parameter ξ. Consistently with estimates by Blanchard and Diamond (1990) we set this parameter to 0.4. We set the firm matching rate, $q(\theta)$, to 0.7 which is the value used by Den Haan, Ramey and Watson (2000). The probability for a worker of finding a job, $\theta q(\theta)$, is set equal to 0.6, which implies an average duration of unemployment of 1.67 as reported in Cole and Rogerson (1999). With those values it is possible to determine the number of vacancies as well as the vacancy/unemployment ratio. We set the exogenous separation probability, ρ^x, to 0.08 and the steady state overall separation rate, $\rho(\tilde{a})$, to 0.1. With those values it is possible to obtain the endogenous separation rate, $\rho^n(\tilde{a}) = \frac{(\rho(\tilde{a})-\rho^x)}{(1-\rho^x)}$, and the threshold value, $\tilde{a} = F^{-1}(\rho^n)$. The idiosyncratic shock is distributed as a lognormal with unitary mean and standard deviation equal to 0.20. Finally we set the degree of wage rigidity, λ, equal to 0.5 as benchmark value.

Labor market institutions. As in Krause and Lubik (2005) the unemployment benefit is obtained as solution to the steady state. In particular we assign values for the bargaining power, ς, we then compute the unemployment benefit parameter, b, from the steady state job destruction equation so as to generate values for the $\frac{b}{w}$ ratio which are in the range of the ones reported by Nickell and Nunziata (2007) over the sample 1998-2004.

Exogenous shocks and monetary policy: We consider domestic and foreign aggregate productivity shocks, z_t and z_t^*. We follow Backus et al. (1992) and calibrate their standard deviations to 0.008, their correlation to 0.258 and their persistence to 0.95. We also consider an i.i.d. common monetary policy shock, m_t, whose standard deviation is calibrated using data from Mojon and Peersman (2003). Following several empirical studies for Europe (see Clarida et al. (2000), Angeloni and Dedola (1999) and Andrés, López-Salido and Vallés (2006) among others) we set the interest rate smoothing parameter, χ, equal to 0.8.

2.4 Quantitative Properties of the Model

In this section we analyze the main quantitative properties of the model and the impulse response functions of the main variables. We have two goals in mind. First, we want to validate the model, showing that it mimics well the main business cycle properties of the euro area economy. Second, we calculate impulse responses to provide a first assessment on how different values of the replacement rate generate different responses of wages, marginal costs, and inflation, to better understand the structural links among these variables. Having done this, the next section will be devoted to assess whether the model can replicate the stylized facts shown earlier.

Table (2.2) shows standard deviations of selected variables (relative to output) for euro area data[16] and for the model economy. In this case our calibration for the replacement rate is the average value across euro area countries obtained from Nickell and Nunziata (2007) data. Standard deviations for the model have been computed by simulating the model 100 times for 200 periods and calculations are based on Hodrick-Prescott filtered series. As customary in the real business cycle literature, we simulate both technology and common monetary policy shocks, all of which are calibrated on euro area data (see calibration section). In computing the statistics for this table we assumed complete symmetry between the two countries for all parameters, including those of the labor market – in the next section instead we will allow these parameters to vary to show their impact on the relevant volatilities. This implies that the sizes of the standard deviations for the home and the foreign countries are very similar[17]. We observe that the model is able to replicate well the standard deviations of output, consumption, employment and inflation in the euro area[18]. Another way to assess the quantitative properties of our model economy concerns the model ability to replicate the international co-movements. It is well-known that output and employment are positively correlated across countries (see

[16]Standard deviations of euro area data for GDP, consumption, inflation are taken from Agresti and Mojon (2001) who computed them by averaging standard deviations for all euro area countries. The data used in Agresti and Mojon (2001) are for the period 1970-2000. The standard deviation for employment is taken from Backus et al. (1992).

[17]Although not the same since the productivity shocks have a correlation of 0.25.

[18]Unfortunately it is not possible to calculate empirical standard deviations for vacancies and labor market tightness since it is not possible to find long enough series for euro area countries. The model standard deviations are somewhat lower than the ones calculated by Krause and Lubik (2005) for the U.S. (8.27 for vacancies and of 14.96 for labor market tightness).

Backus et al. (1992) and Faia (2007)). Our simulations (with both productivity and monetary policy shocks) show that our model economy generates a correlation between home and foreign output of 0.53 and a correlation between home and foreign employment of 0.93.

We now use impulse response analysis to provide a first assessment of the differential impact of different replacement rates on the two countries dynamics. We calibrate the model so that the home country has a smaller replacement rate than the foreign country, while in all the other parameters the two countries are symmetric. In particular we set the replacement ratio for the home and the foreign country equal to 0.22 and 0.77.

We start by considering positive technology shocks. Figure 2.3 we report the impulse response functions of domestic variables to domestic technology shock (solid line in each panel) and of foreign variables to a foreign technology shocks (dashed line in each panel).

By plotting in the same panels impulse responses to shocks of the same size we can appreciate the impact of different replacement rates across countries. Let's start to analyze the impulse responses of domestic variables to a domestic productivity shock. On impact, as we can see from figure 2.3, domestic output rises but domestic unemployment rises and wages fall. The increase in unemployment is due mainly to the assumption of price rigidity (see Galí (2003))[19]. In the subsequent periods prices can fully adjust hence unemployment falls below its steady state level. Real marginal cost decreases because of both the higher productivity and the lower real wages. This mechanism would be observable also in a closed economy but in an open economy framework it is amplified by the terms of trade effect. Because of the

[19] Due to price rigidity, firms in the first period will not reduce the prices as they would have done without adjustment costs. Therefore, aggregate demand increases by less than in the flexible price case. Since the productivity increase allows to produce the same amount with less work this leads to lower employment and real wages.

domestic technology improvement domestic goods become cheaper than foreign ones hence domestic exports and demand increase.

Let's now analyze the dynamic of foreign variables in response to a foreign productivity shock. Since the foreign country has a higher replacement rate this comparison can reveal the role played by replacement rates. As already noted, unemployment rises and wages decline in both countries after a positive technology shock. Since in the home country domestic workers face a lower replacement rate, they also face worst outside option, hence they are willing to accept a larger reduction in wages in order to keep their jobs. Hence in response to a domestic technology shocks domestic wages fall by more than foreign wages under an equal sized foreign technology shocks. Moreover the fall in domestic marginal costs and inflation in response to domestic technology shocks is higher than the fall in foreign marginal costs and inflation under foreign technology shocks.

Figure 2.4 shows the dynamic of home and foreign variables after a monetary policy tightening. In our setting (currency union, same transmission mechanisms), this is a perfectly symmetric demand shock. Output and employment contract in both countries. However domestic wages, marginal costs and inflation fall below the foreign ones. This is because domestic workers face lower replacement rates, hence worst outside options in case of unemployment. This implies that domestic workers are willing to accept bigger reductions in wages in order to keeps their jobs. The higher volatility in domestic wages induces also higher volatility in marginal costs and inflation.

In general we can conclude that under both demand and supply shocks real wages, marginal cost and inflation are more sensitive for countries with lower replacement rates. It is worth noticing that the size of the differentials we obtain from the impulse responses is lower in terms of magnitude than the one observed in the data: this is so since impulse response functions show by construction the response to only one shock at the time. The next paragraph is devoted to show how the model can match the size of the differentials in response to several shocks.

2.4.1 Matching the Data

We conduct our data matching exercise by showing that the model can reproduce the relationship in the data between ratios of volatilities (of real wages, marginal costs and inflation) and ratios of replacement rates across pairs of countries. The reason why we do this instead of simply showing the relationship between replacement rate levels and volatility levels for an individual country is that, when changing the value of the replacement rate in (say) the foreign country, the equilibrium volatilities change both at home and abroad, even if the replacement rate at home remains unchanged. The volatility spillover is stronger if the two economies are closely interconnected, as is the case in EMU. Hence, in order to correctly match the extent to which differences in labor market structures generate differences in volatility for our three variables, we need to be able to approximate well the interpolating curves shown in figure 2.2 (panels a, b and c).

Figure 2.5 (a, b, and c) shows the exponential interpolation curves (alongside with the linear ones) shown in figure 2.2 together with its model-based equivalents. Model-based standard deviations are computed using simulated series with length T=200 and calculations are based on the Hodrick-Prescott filtered series. We shock the model with both technology and monetary policy shocks calibrated on euro area data, as described earlier. Considering both shocks allows us to account for the closest possible match between the data and the model. The range of variation for the ratio of the replacement rates is calibrated so as to match the value reported by Nickell and Nunziata (2007) over the sample 1998-2004. More precisely, we set (b^*/w^*) for the foreign country to 0.77, we then allowed the b/w for the home country to take values ranging between 0.30 and 0.73. We then simulated the model for each pair $[b/w, (b^*/w^*)]$ and computed the standard deviations for both countries. Since in producing figure 2 we always divided for the country with the lower replacement rate, when computing figure 5 we always divide the foreign variables by the home variables in order to make the data and the model results comparable.

As we can see, the model is able to replicate the negative relations found in the data for all the three variables, thereby confirming our mechanism. Interestingly the model-based relations are non-linear and convex with respect to the origin, as our exponential interpolations. The shapes of the theoretical curves broadly (though not perfectly, as one would expect) match the empirical ones[20].

2.4.2 The Impact of Employment Protection

To further assess the ability of our model to replicate empirical facts regarding the impact of labor market institutions on the business cycle we repeated the entire analysis so far described but using instead of the *replacement rate* an indicator of the *employment protection*. This indicator can be considered as a proxy of the *worker bargaining power,* ς, and data are taken again from the dataset of Nickell and Nunziata (2007).

In the theoretical model a positive relation exists between business cycle responses of real wages, marginal costs and inflations on the one side and the sizes of the bargaining power, ς,on the other[21]. Intuitively an increase in the workers' bargaining power increases the value of an existing job relative to the outside option. This

[20]The model generates a negative relation also between absolute levels of real wages, marginal cost and inflation on the one side and the levels of replacement rates on the other. However, the shape of the curve is not convex, but concave relative to the origin. Results are not reported for brevity but are available on request.

[21]Note that in the steady state of our model there is a negative relation between the replacement rate and the bargaining power.

implies that in response to shocks workers are more willing to accept large swings in real wages while keeping the existing jobs.

Data for the EMU countries show an inverse relation between employment protection and replacement rates exactly as in the model[22]. This implies a positive relation between business cycle responses of real wages, marginal costs and inflations on the one side and the employment protection on the other. We therefore conclude that the model implications remain valid even when labor market institutions are proxied by a different and equally important indicator.

Overall our results point out at another interesting dimension of the mechanism featured by our model and confirmed by the data. In our context a country experiences high volatility of wages and inflation if it is characterized by low replacement rates, which implies high protection of incumbent workers (high employment protection and high initial wage) and low protection of searching workers (low unemployment benefit). This is for instance the case of several Mediterranean countries (Italy, Spain and Portugal) as shown in table 2.1. Such countries might seem to have more flexible labour market as their wages respond more to shocks, but they are also characterized by lower variability in job flows. Firms in those countries tend to hire less workers (as in response to shocks firms can adjust over-hours and wages) and for this reason labour markets are characterized by higher sclerosis of job flows[23].

[22] Figures regarding the aforementioned relations are available upon request.

[23] This point is well discussed in recent official documents of the European Community and the European Central Bank concerning labour market reforms. Those documents in fact encourage countries to undertake measures that decrease protection of incumbent workers and increase protection of searching workers (labelled as “flexicurity” reforms) as they allow more flexibility in job flows.

2.5 Conclusions

In this paper we study the role of labor market differences in generating differential inflation volatility among euro area countries. To do this we use a stylized DSGE model where labor market frictions are an important determinant of the dynamics of marginal costs of firms, which in turn are a main driver of inflation. We find that differences in labor market institutions (proxied by the replacement rates, or alternatively by a measure of workers' bargaining power) can generate significant volatility differentials in real wages, marginal costs for firms and inflation when the model is subject to a variety of realistic shocks. The volatilities of the three aforementioned variables tend to be higher when the unemployed is less protected (low replacement rate) or the employed is more protected (high bargaining power). The link between labor market institutions and volatilities embodied in our model approximates well the one observed in the data.

Table 2.1: **Masures of replacement rates (benefit as a ratio to average earnings before taxes taken from Nickell and Nunziata). Average over 1998 to 2004.**

Countries	Replacement rate
Austria	0.72
Belgium	0.77
Finland	0.55
France	0.52
Germany	0.58
Ireland	0.89
Italy	0.41
Netherlands	0.67
Portugal	0.48
Spain	0.39

Table 2.2: **Business cycle properties of the euro area economy and of the model economy.**

	Euro area	Model economy	
Standard deviation		Home country	Foreign country
Output	1.14	1.59	1.61
Consumption	0.78	0.93	0.94
Inflation (GDP deflator)	0.5	0.5	0.49
Employment	0.85	0.87	0.85
Vacancies	...	5.17	5.04
Tightness	...	11.38	11.13

Statistics for the euro area are taken from Agresti and Mojon (2003) except for the standard deviation of employment which is taken from Backus, Kehoe and Kydland (1985).

All standard deviations are relative to output. Statistics from the model are Hodrick-Prescott filtered. and are computed under two correlated productivity shocks and one common monetary policy shock.

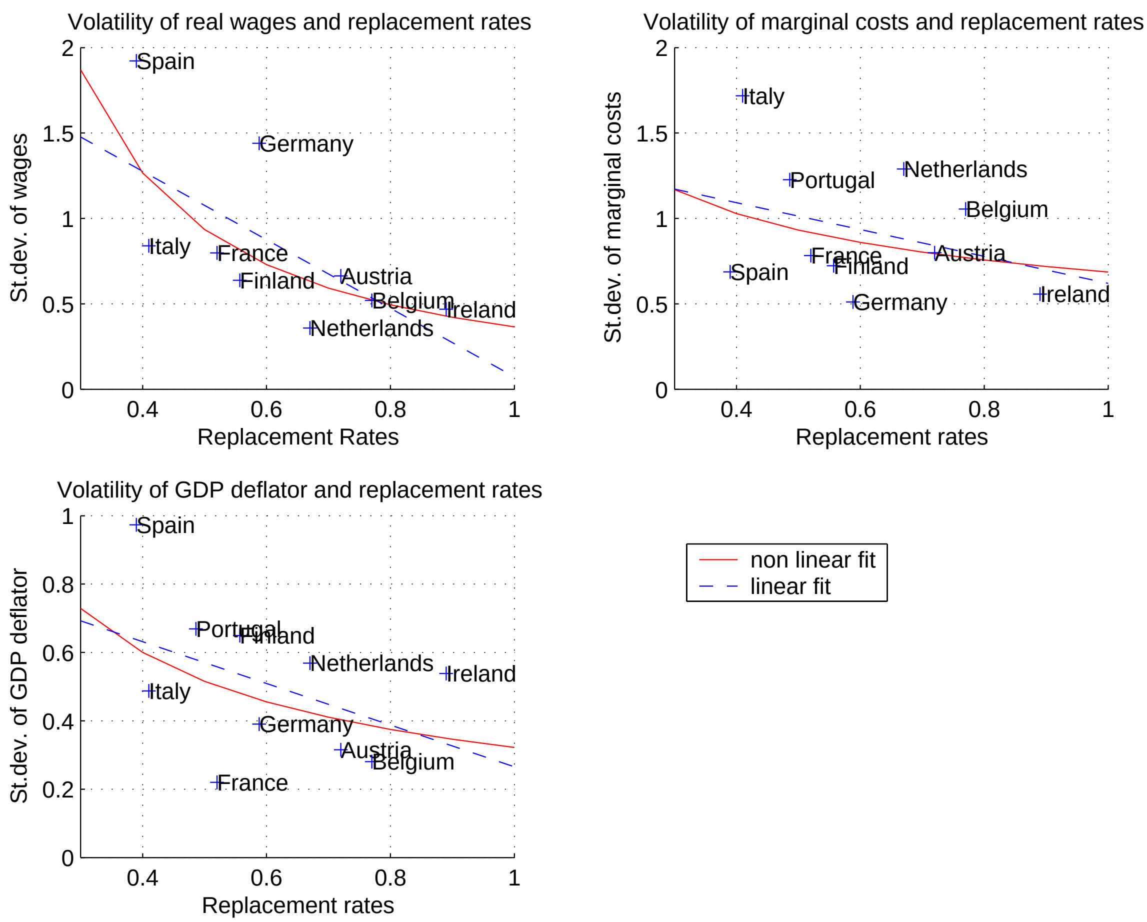

Figure 2.1: Relation between standard deviation of wages, marginal costs and inflation (relative to that of output) and replacement rates for the EMU countries

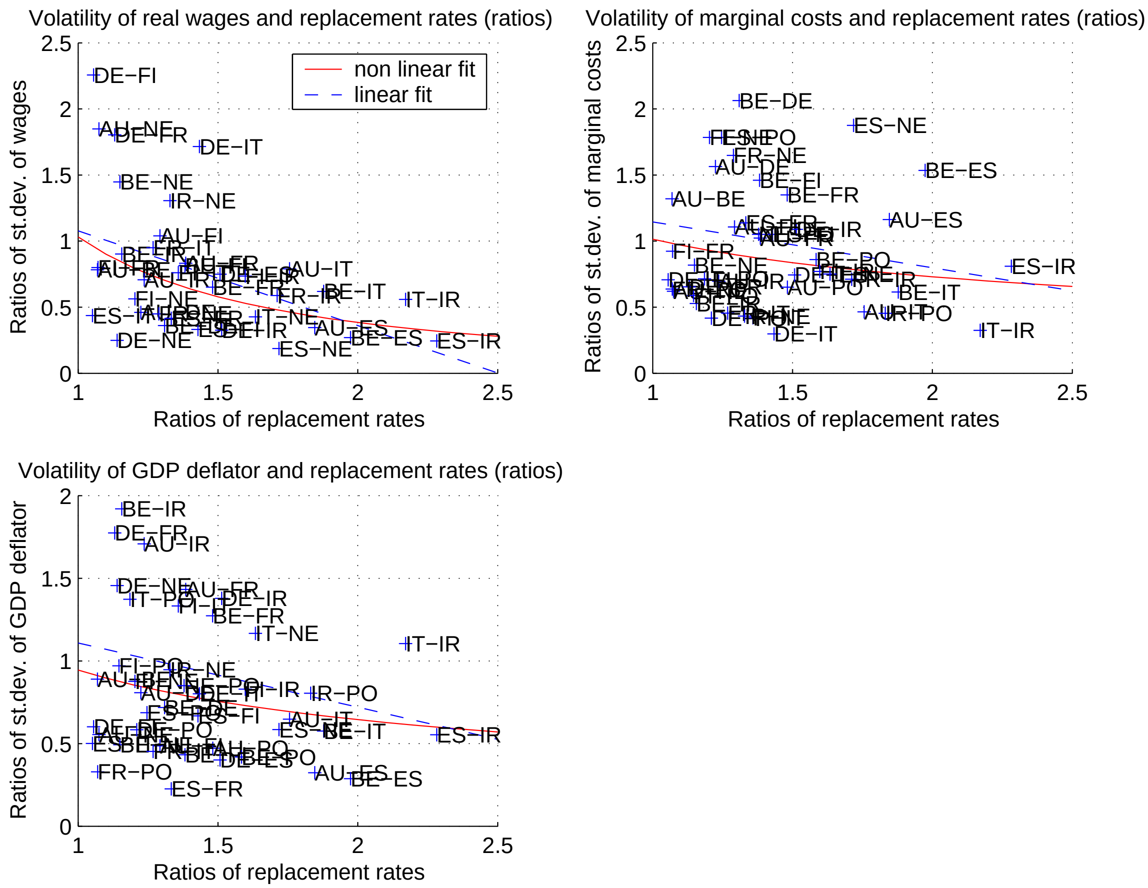

Figure 2.2: Relation between ratios of standard deviation of wages, marginal costs and inflation (relative to that of output) and ratios of replacement rates for the EMU countries

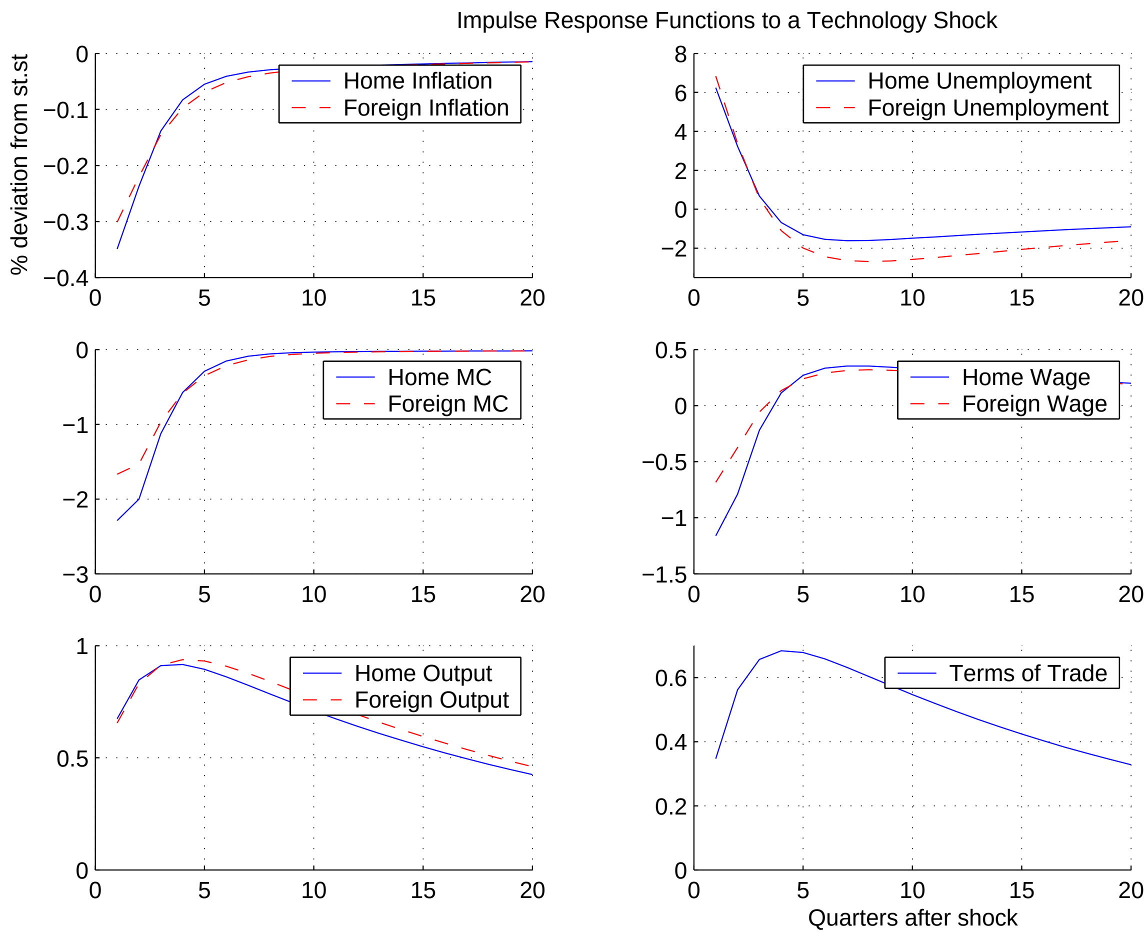

Figure 2.3: Impulse responses of selected domestic and foreign variables to domestic (solid line) and foreign technology (dashed line) shocks

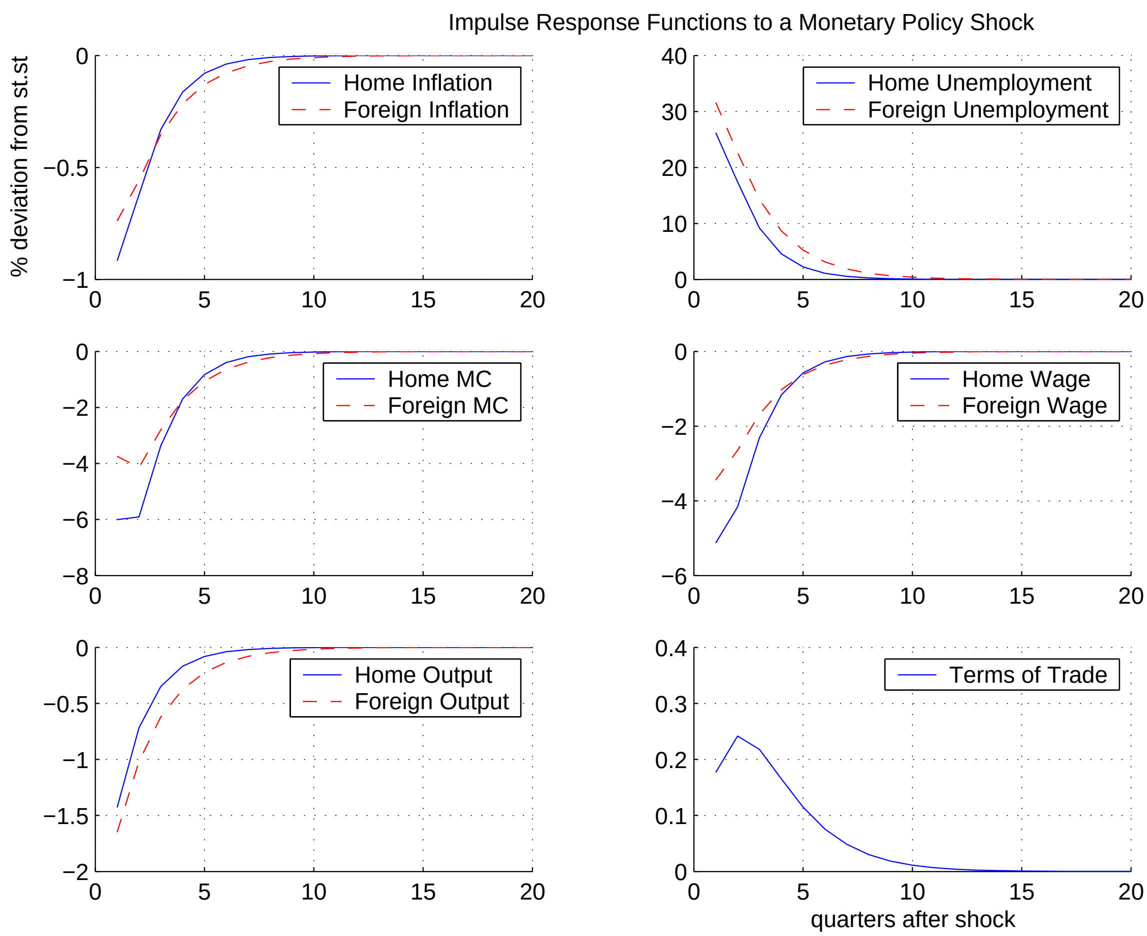

Figure 2.4: Impulse responses of selected domestic and foreign variables to common monetary policy shock

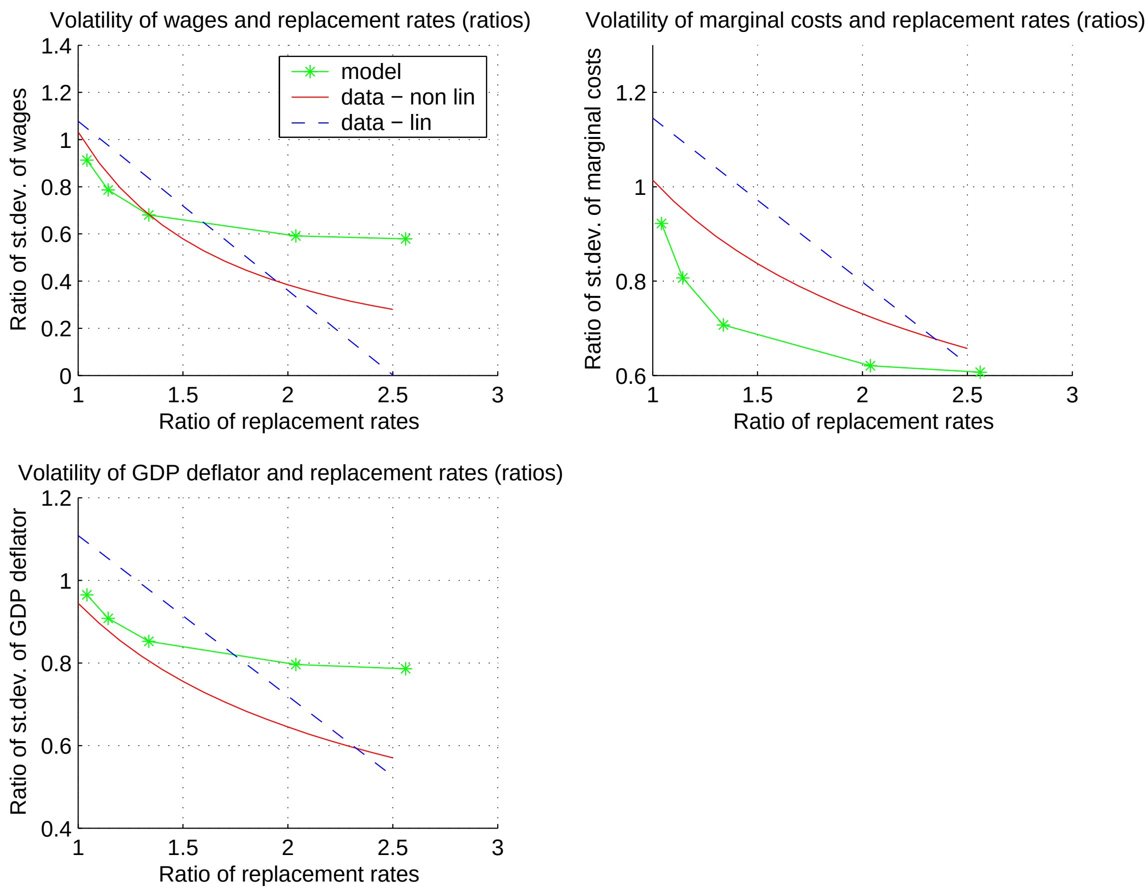

Figure 2.5: Relation between ratios of standard deviation of wages, marginal costs and inflation (relative to that of output) and ratios of replacement rates both in the data and in the model

Chapter 3

Oil price shocks: Demand vs Supply in a two-country model

3.1 Introduction

> *"China's oil demand certainly shot up in 2004, by 15%. That strong growth, along with political crises in Iran and Nigeria, appeared to explain why oil prices have been recently heading towards $70 a barrel again*[1]*".*

The oil price went from 27$ per barrel in January 2000 to 74$ per barrel in July 2006[2]. Such an increase in the price of oil is of the same magnitude as the one experienced during the 70s. But, is this *new oil shock* comparable with the one in the 70s? While in the 70s the rise in oil price was accompanied by a reduction in real GDP and an increase in inflation, the current situation is quite different with no signs of either rising inflation or reduction in real GDP growth[3].

When studying oil price changes, no attention is commonly dedicated to the source of the oil price increase. The implied assumption under this approach is that the only

[1] *"Oil prices - New friendships and petropuzzles" Jan 26th 2006, The Economist.*

[2] Spot Oil Price: West Texas Intermediate, Source: Dow Jones & Company, Release: Wall Street Journal. FRED Economic Data.

[3] See section 3.3 for a detailed analysis of the data.

thing that matters for the economy is the sign (and the magnitude) of the oil price change. The contribution of the paper is twofold: first, to show the failure of this approach in explaining the differences between the oil price changes of the 70s and the current one; second, to propose and alternative approach where a ”step back” with respect to the current literature is taken. Specifically, we develop a model where shocks of different nature can drive an increase in the oil price and we show that while the 70s are consistent with a supply shock, a demand shock delivers dynamics close to the one observed in the 2000. The policy implication of this result is a clear one: to uncover which shocks are the sources of the current rise in oil price is fundamental to understand whether or not the economy is at risk of experiencing a period of recession and high inflation like in the 70s.

The intuition of why different sources of oil price increase can deliver different dynamics is a simple one. Consider an exogenous reduction in the supply of oil. This experiment is consistent with the hypothesis commonly used in the literature to study the oil shocks of the 70s[4]As a consequence, the economy will experience an increase in oil price which will boost marginal costs therefore driving an increase in inflation (both in prices and wages), and a decrease in real wages and GDP. While this is consistent with the experience of the 70s, it is clearly at odds with what we observe today. Consider instead a two country model where an exogenous and persistent increase in the productivity of the foreign country drives an increase in foreign GDP. If this shock is very persistent (like it seems to be the case for some non-OECD countries like e.g. China and India), then several things will happen at the same time. First, given the increase in production, the foreign country will increase the oil demand therefore driving up the oil price. On the home economy this will have the same consequences of an oil price increase driven by a reduction in oil supply,

[4]For a detailed review of the literature on oil shocks presenting also alternative hypothesis see section 3.2.

i.e. marginal costs will increase therefore domestic inflation will increase too while GDP and real wages will decrease. But this is not the end of the story. Indeed the second consequence will be a reduction in the price of the imported goods given that now the foreign country is more productive. As a result, CPI inflation in the home country may actually decrease therefore generating an increase in real wages. Finally, since the foreign country is richer, there will be an increase in the demand for home produced goods from foreign consumers and therefore home output will increase too. Therefore, the dynamics of oil price, inflation, real wages and GDP observed in the 2000s may be consistent with an increase in oil demand driven by the increase in productivity in countries like China and India[5].

Up to now the theoretical literature (and also most of the empirical one[6]) has always considered exogenous increases to the oil price driven by reduction in oil supply and has tried to understand whether the oil price crises can be considered responsible for the high inflation and low output of the 70s. The novelty of this paper is to develop a theoretical model where the oil price is modelled endogenously therefore, allowing for the study of factors different from oil supply shocks that can affect its dynamics.

To this purpose, a two-country model like the one developed in Clarida et al. (2002) is used, with two main differences. First, in the production sector two inputs are needed, labour and oil. Oil is considered as a traded good therefore, the price is determined internationally and will depend on the demand of both countries (the importance of each country oil demand depending on the relative size of the country). In order to simplify the analysis, no one of the two countries is an oil producer. It is assumed that at each point in time there is a world oil endowment which may

[5]Of course, at the same time more then one shock is responsible for the behaviour of the oil price and of the macro variables. Here we are focusing on the shocks we think to have played a major role in the oil price increase in the different years.

[6]For an exception see Kilian (2007c).

be subject to exogenous shocks. As in Clarida et al. (2002), firms' pricing decisions are subject to Calvo staggering. This is important to link the behaviour of real and nominal variables in order to study simultaneously the behaviour of GDP and inflation. Second, in order to have the monetary authority facing a non trivial trade off between inflation and output gap stabilization, the presence of a wage mark-up fluctuating over time is endogenised by allowing for wage rigidities, as in Erceg et al. (2000). The reason for this is twofold. First, it allows to study also the dynamic of real wages and wage inflation in a realistic environment. Second, it will make it possible to study how the conduct of monetary policy is going to affect the results in further extensions.

For the shake of simplicity, the main results of the model are derived under the assumption of perfect symmetry among countries and using a simple interest rate rule targeting national CPI inflation in each country. Two kinds of shocks are considered. The first one is a shock to the oil supply, calibrated such that the real price of oil will increase, on impact, by 100%. Such shock is an aggregate disturbance that, given the assumed symmetry, affects both countries in the same way. The second shock is an increase in foreign productivity calibrated in order to match the average quarterly increase in China GDP between 2001 and 2005. Since this shock is meant to represent the increase in productivity in China, a very high autocorrelation coefficient is assumed for this shock, as an approximation for a process that is likely to be stationary only in first differences. The behaviour of real oil price, output, CPI inflation, GDP deflator inflation (from now on domestic inflation), real wages and wage inflation under the two shocks is analysed. The focus is on the behaviour of the variables of the Home country that is supposed to represent the U.S.

After the shock to oil supply the price of oil rises, on impact, by 100%, and then goes back to its steady state level in one year. This is consistent with the experience of the 70s, where the oil price increase was sharp, but not with the current experience, where the real oil price rise is more smooth and prolonged[7]. Because of the increase in the production costs, the home economy experiences a sharp decrease in output, an increase in price inflation (both CPI inflation and domestic inflation) and wage inflation and a decrease in real wages. The model matches the change in those variables experienced in the U.S. after the 1973-74 shock. It does not match instead the sign of the movements in the same variables after the 2003 shock.

On the contrary, after the shock to foreign country productivity (matching the increase in production in China in the last years), the model predicts an increase in oil price that can account for a 40% increase in the oil price in the period considered. It also generates a reduction of CPI inflation and an increase in real wages, due to the fact that home consumers can now buy foreign produced goods at a cheaper price. Finally, both output and domestic inflation increase. Also for these two variables, the sign is the same as the one experienced by U.S. variables, therefore confirming the original hypothesis that a change in the nature of the shocks driving up oil price is a good candidate to understand the differences between the oil shocks of the 70s and the oil shock of the 2000s. It also tells us that we should not always expect an increase in inflation and a decrease in output every time we observe an increase in the price of energy goods.

Clearly, the model in its current form can not account for the total increase in oil price of the last few years but this is not surprising for at least two reasons: first, we are using an extremely simple version of a two-country model; second, most likely the increase in China's oil demand is not the only determinant of the current increase in oil price.

[7]The current increase in oil price started in 2002 and is not yet over i.e., more than a one time shock is a 5 year period of price increase. In this period, the maximum quarter-by-quarter increase has been 18% (second quarter of 2002) while the average quarterly increase has been around 7%. Instead, in the 1973 oil shock, oil price increased by 82% in the first quarter of 1974.

In order to keep the model as tractable as possible, it has been derived under a set of simplifying assumptions. Two important ones are the assumptions of perfect risk sharing and perfect symmetry across the two countries, two hypothesis that are clearly unrealistic especially given that the home country is supposed to represent the U.S. while the foreign country represents China. In order to test the quantitative implications of the model it will be important to relax at least the assumption of home bias. Indeed, even if China imports have increased and are most likely to keep on increasing in the future, up to now it has been mostly an increase in intermediate goods rather than in final consumption goods therefore, the model without home bias is likely to overestimates the impact of China growth on U.S. output. It also will not be able to capture the right magnitude in the dynamics of imports and exports between the two countries, whose dynamics are important in driving the behaviour of CPI. A version of the model with home bias is currently under development.

The paper proceeds as follow: section 3.2 reviews the related literature, section 3.3 presents some data evidence to clarify the different behaviour of the U.S. main variables during the different oil shock episodes, section 3.4 contains the model, section 3.5 shows the impulse responses of the variables to different types of shocks and section 3.6 concludes.

3.2 Related literature

There have been several papers studying the impact of oil shocks on the economy. Most of the literature has focused on the oil shock episodes of the 70s. An important contribution is the one by Hamilton (1983). He addresses two questions: first, the causes of the oil shocks between 1948 and 1972; second, whether there is a causality relation between the oil price increase and the recession episodes experienced by the U.S. His conclusions are first, that the rise in oil price was driven by either political crises in the Middle East or OPEC decisions, both bringing about a reduction in oil supply therefore pushing up the oil price. Second, those shocks appear to be important in explaining the periods of recession and high inflation experienced by the U.S. economy. For a different view on the relation between oil price and macroeconomy after 1973 see Hooker (1996) (and the reply by Hamilton (1996)) and Barsky and Kilian (2004)[8].

Bernanke, Gertler and Watson (1997) and Barsky and Kilian (2002) argue that the conduct of monetary policy is crucial in explaining the periods of recessions and high inflation occurred after the oil shocks of the 70s.

On the theoretical side, Rotemberg and Woodford (1996) and Finn (2000) show that oil price shocks have a substantial impact on economic activity despite the fact that the proportion of oil used in the production process is relatively small. Both papers are in closed economy and with no nominal rigidities. Also, since they are interested in supply shocks, they use an exogenous process for the oil price. The paper by Backus and Crucini (2000) is a three-country model with no nominal rigidities, that shows that oil price shocks account for a big proportion of terms of trade volatility. They endogenise the oil price through the presence of a third country producing oil. Since there are no nominal rigidities this framework is not suitable for monetary policy analysis. Another work is the one by Leduc and Sill (2004). It is again a closed economy with an exogenous process for the oil price, but it is the first one with nominal rigidities. The main objective of the paper is to see whether the recessionary consequences of an oil shock are only due to the oil shock itself, or also to how monetary policy is conducted. They use a DSGE model to show that monetary policy plays only a secondary role in the recessionary process, but that a monetary authority more concerned about inflation better deals with the problem. Also in this

[8] See also Kilian (2007a) and Kilian (2007b)

case, the focus is on supply shocks, with the price of oil modelled as an exogenous process.

Two papers more closely related to the present one are Blanchard and Galí (2007) and Kilian (2007c). Like the present paper, Kilian (2007c) underlines the importance of identifying supply vs demand shocks to oil price. He provides a decomposition of real oil price into: oil supply shocks; shocks to the aggregate global demand for industrial commodities; demand shocks that are specific to the oil market (i.e., precautionary oil demand). Using this decomposition he claims that, while the oil price increase in the 70s is mainly do to precautionary demand increase, in the current increase a crucial role is played by aggregate demand shocks. However, to be notice is that the identified aggregate demand shocks "rise U.S. real GDP growth in the first year after the shock, but lower it in the second year. They also cause a persistent increase in CPI inflation[9]". This is not really consistent with the current U.S. situation where we do not observe an increase in CPI (see section 3.3). Blanchard and Galí (2007) try to understand the difference between the various oil shocks but their focus (differently from the present paper) is on the fact that the oil shocks seem to have a far lower impact on economic activity now than in the 70s[10] (in line with the literature on the great moderation) rather then on understanding the different directions in the movements of output and CPI following an oil price increase. They start from the assumption that the source of the change in oil price is always the same, i.e. an exogenous increase in oil price, and study how a different environment can affect the transmission of the same shock. As possible candidates, they consider differences in the monetary policy, in the degree of wage rigidity and in the proportion of oil used in the production and show that a change in each of them can reduce the volatility

[9]Kilian (2007c), page 3.

[10]See also De Gregorio, Landerretche and Neilson (2007) for a study of the lower passthrough from oil price to CPI in the 2000s.

of both prices and quantities in response to the same oil shock. However, given that they always focus on supply shocks, their model is not suited to understand how an oil price increase can be accompanied by an increase in output and a reduction in CPI like it happened in the U.S. in 2000s.

To be noticed is that the story presented in Blanchard and Galí (2007) and the one developed in this paper are complements rather than substitutes. Indeed, it is reasonable to expect that shocks of different nature are hitting the economy at the same time, and also that the structure of the economy is evolving over time. The current increase in oil price is likely to be the consequence of both supply and demand shocks. The kind of changes in the structure of the economy analysed by Blanchard and Galí (2007) reduce the reaction of inflation and GDP to the oil price increase, i.e. reduce the increase in inflation and the decline in output following the oil price increase. If at the same time also a demand shock boosting oil price is at work, we show in the present paper that inflation decreases and output increases. The two shocks together increases oil price but offset each other in terms of movements in inflation and output and this explain the reduction in the volatility of those variables. Finally, if the demand shock is sufficiently strong, the overall result can be a positive growth in GDP and low or decreasing inflation, as observed in the U.S. in 2000s.

3.3 Stylized facts

Figure[11] 3.1 reports the behaviour of oil price from the first quarter of 1960 to the first quarter of 2007[12]. The top panel represents the nominal oil price expressed in dollars per barrel. In the bottom panel the nominal oil price has been divided by the CPI in order to express it in real terms. Taking logs it is possible to interpret the

[11] Tables and figures follow at the end of the chapter.

[12] See appendix B for a detailed description of the data used in this chapter

differences between two periods as percentage changes. The 1960 is the base year.

Following Blanchard and Galí (2007), we define an oil shock as an episode where the overall increase in oil price has been of more then 50% and has lasted for more than one year. Following this criteria four oil shocks are identified and for each of them the date at which the 50% threshold is reached has been reported in the graph. For each oil shock, table 3.1 reports the overall increase in the oil price. In terms of the magnitude of the oil price increase, the four episodes are all alike, with an increase of oil price of around 100%. The main difference is that, while in the first two episodes (and, too a lesser extend, also in the third one) few quarters were needed to reach the 100% increase, in the last one the increase is much smoother. Therefore, the dynamics of the change in oil price in the last episode seems to differ from the first two.

The next step, after having identified the shock episodes, is to look at what happened to other variables during those periods. In pictures 3.2, 3.3 and 3.4 the following U.S. variables are represented: CPI inflation, GDP deflator inflation, real GDP growth rate, real wage[13] and wage inflation. The inflation rates and the growth rate are annualized rates while the real wage is expressed in logs with the 1960 as base year.

The first two episodes of oil price increase coincide with an increase in all inflation variables and a decrease in GDP growth and real wage. On the contrary, the last episode coincides with a positive GDP growth rate, an increasing real wage and low inflation rates. Things are even more clear looking at the results of tables 3.2 and 3.3. Following the same methodology used by Blanchard and Galí (2007), for each variable, table 3.2 (3.3) presents the percentage change between the average value one (two) year(s) after the shock and the average value one (two) year(s) before the shock.

[13]Computed dividing the nominal hourly earnings by the CPI.

As reference quarter it has been used the one where the oil price reached the 50% increased needed to qualify the increase as an oil shock. Therefore, the interpretation of the table 3.2 is that average CPI inflation in the 1974 (the year after the shock) was 3.2 percentage points higher then it was the year before. At the same time the real GDP growth was 6 percentage points lower than in the previous year. During the first two oil shocks the U.S. economy experienced a period of stagflation with rising inflation and decreasing output. At the same time the real wage also decreased after the oil shocks while wage inflation was rasing. Results are basically unchanged if you consider a longer horizon (table 3.3). Things are drastically different in the last two shocks and in particular in the one of 2003. During this last oil price increase, the U.S. economy experienced a positive GDP growth, an increase in real wages, a decrease in wage inflation and either a decrease (at the 4 quarters horizon) or only a moderate increase (at 8 quarters horizon) of CPI inflation.

Those simple observations underline how much different is the current experience from the oil shocks of the 70s.

One last thing it is interesting to look at, is the evolution of oil consumption over time. Figure 3.5 represents the average yearly world consumption (expressed as thousand barrels per day), with the contribution of OECD and non OECD countries reported. While, after the oil shocks of the 70s, world oil consumption decreased, this is not the case in the 2000s where, even with an increase of the oil price of more then 100%, the world oil consumption has increased steadily. This of course is not surprisingly given that in the 70s several countries experienced a recession while this is not the case today. Still, after a supply shock we should not expect to observe an increase in oil consumption. Perhaps more importantly, it emerges clearly from the picture that most of that increase has been driven by the growth in consumption of non OECD economies. In particular, while non OECD consumption in the 70s was accounting for only 26% of world consumption, it accounts for more than 40% in 2000s. As a consequence, the dynamic of non OECD countries plays now a more important role in shaping the behaviour of oil price than it did in the 70s-80s.

To sum up, while the oil shocks of the 1970s are associated with increasing inflation (both price and wage inflation), decreasing real GDP and decreasing real wage, the opposite is true for the current increase in the oil price where the US economy is characterized by stable (even decreasing) inflation, increasing real wage and positive real GDP growth. In the next section a model is provided to give some insights on how this is possible.

3.4 The model

The world is populated by a continuum $[0, 1]$ of agents. Agent $h \in [0, n]$ lives in the home country (H) while agent $h \in (n, 1]$ lives in the foreign country (F). Therefore, the two countries may have different size. For everything else, perfect symmetry is assumed. Variables are expressed in per capita terms. The reference model is Clarida et al. (2002). We follow their modelling strategy assuming that in each country there are as many final goods producers as households. In the final goods sector perfect competition is assumed. In order to keep the model as simple as possible, it is assumed that in each period there is a world endowment of oil. The world oil price is determined in equilibrium given the oil demand from firms in the two countries. The profits from selling oil are redistributed in each period among all the households of the two countries evenly (i.e. the per-capita share of profits is the same for home and foreign households), as a lump sum transfer.

3.4.1 Household problem

Each household supplies a differentiated labour service to each of the firms in the country. As usual in this class of models, labour is immobile across countries. The elasticity of substitution across workers is θ_w. Since each household acts as a monopolist in the supply of his labour, he chooses the wage in order to maximize the lifetime utility, subject to the labour demand schedule.

Household h in the domestic economy chooses $\{C_t, W_{H,t}(h), D_{t+1}\}$ in order to maximize:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t(h)^{1+\varphi}}{1+\varphi} \right) \right\} \tag{3.1}$$

subject to:

$$P_t C_t + E_t[Q_{t,t+1} D_{t+1}] = (1+\tau_w) W_{H,t}(h) N_t(h) + D_t - T_t + \Gamma_t + \Upsilon_t \tag{3.2}$$

$$N_t(h) = \left[\frac{W_{H,t}(h)}{W_{H,t}} \right]^{-\theta_w} N_t \tag{3.3}$$

with:

$$C_t = C_{H,t}^n C_{F,t}^{1-n} \qquad P_t = \kappa^{-1} P_{H,t}^n P_{F,t}^{1-n} \qquad W_{H,t} = \left[\frac{1}{n} \int_0^n W_{H,t}(h)^{1-\theta_w} dh \right]^{\frac{1}{1-\theta_w}} \tag{3.4}$$

where $Q_{t,t+1}$ is the stochastic discount factor, D_t is the payoff in t of a portfolio held in $t-1$ and $\kappa \equiv n^n (1-n)^{1-n}$. Equation (3.3) is the labour demand, obtained solving the cost minimization problem of the firms. τ_w is a subsidy to labour that can be used by the fiscal authority in order to offset the distortion created by the presence of monopolistic competition in the labour market. Γ_t and T_t are two lump-sum components of household income representing, respectively, dividends from ownership of firms and taxes. Υ_t is the lump-sum transfer from the redistribution of profits from the sale of oil. Note the Cobb-Douglas aggregator for consumption implies the following assumptions: unit elasticity of substitution between home and foreign produced goods; no home bias in consumption; the number of final producer firms coincide with the number of households in each country. Far from being realistic, those assumptions are imposed here only for the sake of simplicity.

Consumption decision and intertemporal optimization

From the expenditure minimization problem we obtain:

$$P_{H,t}C_{H,t} = nP_tC_t \qquad P_{F,t}C_{F,t} = (1-n)P_tC_t \tag{3.5}$$

while, combining the first order conditions with respect to C_t and D_{t+1}, we find the standard Euler Equation:

$$1 = \beta R_t E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right] \tag{3.6}$$

with $R_t = \frac{1}{E_t(Q_{t,t+1})}$.

Wage decision

Following Erceg et al. (2000), it is assumed that in each period only a fraction $1-\xi_w$ of households can reset wages optimally, while for the others $W_{H,t}(h) = W_{H,t-1}(h)$. Therefore, each household maximizes its lifetime utility taking into consideration that, with probability ξ_w^T, in period T his wage will still be $W_{H,t}(h)$. Given this, the first order condition with respect to wage is:

$$E_t \sum_{T=0}^{\infty} (\beta\xi_w)^T \left[C_{t+T}^{-\sigma} \frac{W_{H,t}(h)}{P_{t+T}} (1-\Phi_w) - N_{t+T}(h)^{\varphi} \right] N_{t+T}(h) = 0 \tag{3.7}$$

with $1-\Phi_w=(1+\tau_w)\frac{\theta_w-1}{\theta_w}$. When $\Phi_w=0$ the fiscal authority completely offset the distortion caused by monopolistic competition in the labour market.

When wages are flexible, $T=0$ and equation (3.7) becomes:

$$\frac{W_{H,t}(h)}{P_t}=N_t(h)^{\varphi}C_t^{\sigma}\frac{1}{1-\Phi_w} \tag{3.8}$$

and $W_{H,t}(h)=W_{H,t}$ and $N_{H,t}(h)=N_{H,t}$ $\forall h\in[0,n]$.

Under sticky wages we need to log-linearize equation (3.7), obtaining the following wage inflation equation:

$$\pi_{w,t}=-\lambda_w\widehat{\mu}_{w,t}+\beta E_t[\pi_{w,t+1}] \tag{3.9}$$

where $\widehat{\mu}_{w,t}=\log(W_{H,t})-\log(P_t)-\varphi\log(N_t)-\sigma\log(C_t)+\log(1-\Phi_w)$, $\pi_{w,t}$ is the log of wage inflation, and $\lambda_w=\frac{1-\xi_w}{\xi_w}\frac{1-\beta\xi_w}{1+\varphi\theta_w}$.

International tradability of state-contingent securities

Because of international tradability of state-contingent securities, the intertemporal condition for foreign consumers can be written as:

$$\beta\left[\frac{C^*_{t+1}}{C^*_t}\right]^{-\sigma}\frac{P^*_t}{P^*_{t+1}}\frac{e_t}{e_{t+1}}=Q_{t,t+1} \tag{3.10}$$

where e_t is the nominal exchange rate. Since there is no home bias in consumption and we assume that the law of one price holds, i.e. $P_t=P^*_te_t$, then $C_t=C^*_t \quad \forall t$.

3.4.2 Firm problem - Final goods sector

Intermediate home produced goods are aggregated into final goods using the following technology:

$$Y_t=\left[\int_0^1 Y_t(j)^{\frac{\theta_p-1}{\theta_p}}dj\right]^{\frac{\theta_p}{\theta_p-1}} \tag{3.11}$$

In both countries there is a continuum $[0,1]$ of producers in the intermediate sector. In each country the final goods are produced using only intermediate goods produced within the country. There is a continuum $[0,n]$ of final good producers in the home country and a continuum $(n,1]$ in the foreign country. The final goods sector operates in perfect competition. Profit maximization yields to:

$$Y_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta_p} Y_t \tag{3.12}$$

with $P_{H,t} = \left[\int_0^1 P_{H,t}(j)^{1-\theta_p} dj\right]^{\frac{1}{1-\theta_p}}$.

3.4.3 Firm problem - Intermediate goods sector

Intermediate goods sector firms produce accordingly to the following technology:

$$Y_t(j) = \left[A_t N_t(j)\right]^{\alpha} O_{H,t}(j)^{1-\alpha} \tag{3.13}$$

where $O_{H,t}(j)$ is the oil demand of firm "j", $N_t(j) = \left[\frac{1}{n}\int_0^n N_{tj}(h)^{\frac{\theta_w-1}{\theta_w}}\right]^{\frac{\theta_w}{\theta_w-1}}$ is firm "j" labour demand and the technology process is defined as:

$$a_{t+1} = \rho_a a_t + \varepsilon_{A,t}. \tag{3.14}$$

with $a_t \equiv \log(A_t)$ and where $\varepsilon_{A,t}$ is an i.i.d shock with zero mean. Whenever $\alpha = 1$ (i.e. oil is not used in the production function) we are back to the standard case. Each firm has to choose how to optimally combine labour and oil and, also, how much to demand of each labour type. Solving the cost minimization problem leads to:

$$\frac{W_{H,t}}{P_{o,t}} = \frac{\alpha}{1-\alpha}\frac{O_{H,t}(j)}{N_t(j)} \tag{3.15}$$

$$N_{tj}(h) = \left[\frac{W_{H,t}(h)}{W_{H,t}}\right]^{-\theta_w} N_t(j) \tag{3.16}$$

where $P_{o,t}$ is the price of oil (it is determined endogenously when computing the equilibrium in the oil market). Integrating (3.16) over all firms, we obtain the labour demand schedule for worker h, (3.3).

Marginal cost

Using (3.15) we can derive the following expression for firm nominal marginal cost:

$$MC_{H,t}(j) = \frac{1}{\alpha}\left[\frac{\alpha}{1-\alpha}\right]^{1-\alpha}\frac{1}{A_t^{\alpha}}W_{H,t}^{\alpha}P_{o,t}^{1-\alpha} \tag{3.17}$$

As standard in this class of models, the marginal cost is not firm specific. When $\alpha = 1$ the expression for the marginal cost simplifies to the usual $MC_{H,t} = \frac{W_{H,t}}{A_t}$.

Pricing decisions

Firm j production is small with respect to the world production and the same is true with respect to firm j oil demand. Therefore, when undertaking production decisions, firm j takes oil price as given. This means that pricing decision is isomorphic to the one we obtain in the standard case. This implies that, assuming Calvo price setting and being ξ_p the probability of not being able to reoptimize next period, if firm j is allowed to reoptimize in t, it will choose $P_{H,t}(j)$ such that:

$$E_t \sum_{T=0}^{\infty} \xi_p^T Q_{t,t+T} Y_{t+T}(j)\left[P_{H,t}(j) - \frac{1}{1-\Phi_p}MC_{t+T}\right] = 0 \tag{3.18}$$

with $1-\Phi_p = (1+\tau_p)\frac{\theta_p - 1}{\theta_p}$. When $\Phi_p = 0$, the fiscal authority is completely offsetting the distortion coming from the presence of monopolistically competitive goods market. Under flexible prices equation (3.18) simplifies to:

$$P_{H,t} = \frac{1}{1-\Phi_p}MC_t \tag{3.19}$$

i.e. the price is a constant mark-up over the marginal cost.

To solve the model under sticky prices, we need to log-linearize equation (3.18) around its the steady state, obtaining the Phillips Curve on home inflation:

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda \widehat{mc}_t \tag{3.20}$$

where $\pi_{H,t} = \log \frac{P_{H,t}}{P_{H,t-1}}$, $\lambda \equiv \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}$, and $\widehat{mc}_t = \log MC_t - \log P_{H,t} - \log(1-\Phi_p)$ is the log-deviation of the real marginal cost from the flexible price allocation.

3.4.4 Equilibrium conditions

Oil market equilibrium

Recall that up to now all the variables have been expressed in per-capita terms. As a consequence, to compute the world oil demand we need to multiply the per-capita oil demand coming from each country by the country size. The oil demand of the world economy is therefore:

$$O_t^d \equiv n \int_0^1 O_{H,t}(j)dj + (1-n) \int_0^1 O_{F,t}(j)dj \tag{3.21}$$

Since the focus is not on the consequences for an oil producer country of an increase in the oil demand, by assumption none of the countries is producing oil. To simplify the model as much as possible, it is assumed that at each point in time there is a world oil endowment O_t^s. We already clarified when studying the household's optimization problem that profits from selling oil $P_{o,t} * O_t^s$ are evenly redistributed as lump sum transfer to the world consumers. The reason for this is twofold: first, we do not want to deal with a third country producing oil and second, we do not want to introduce a source of asymmetry across the two countries, this is why the amount of per-capita profits redistributed is the same across the two countries. To account for supply shocks to the oil price, an exogenous, i.i.d. shock ξ_t to the otherwise constant oil endowment is introduced. In order not to complicate the analysis too much, oil is assumed to be non storable i.e., oil supplied in period t is consumed in the same period. The world oil supply is defined by the following process:

$$O^s_{t+1} = (O^s_t)^{\rho_o} e^{\xi_{t+1}} \tag{3.22}$$

where, ξ_t is an i.i.d. exogenous shock to the supply of oil. When $\xi_t = 0 \forall t$, $O_t = \overline{O} = 1 \forall t$.

The total oil demand of home country is:

$$O^d_{H,t} \equiv n \int_0^1 O_{H,t}(j)dj = n \frac{1-\alpha}{\alpha} \frac{W_{H,t}}{P_{o,t}} N_t \tag{3.23}$$

The total oil demand of foreign country is[14]:

$$O^d_{F,t} \equiv (1-n) \int_0^1 O_{F,t}(j)dj = (1-n) \frac{1-\alpha}{\alpha} \frac{W^*_{F,t}}{P^*_{o,t}} N^*_t \tag{3.24}$$

For the oil market to be in equilibrium $P_{o,t}$ must verify[15]:

$$\frac{P_{o,t}}{P_t} = \frac{1}{O^s_t} \frac{1-\alpha}{\alpha} \left[n \frac{W_{H,t}}{P_t} N_t + (1-n) \frac{W^*_{F,t}}{P^*_t} N^*_t \right] \tag{3.25}$$

An exogenous shock to oil supply will affect the equilibrium price of oil through ξ_t. An exogenous shock to the productivity of one of the two countries will change the quantity produced by both and, therefore, it will affect the oil price through a change in the oil demand. Clearly, the bigger the country, the bigger the consequences of a change in his production.

[14]Real variables with a star refer to the foreign country. For nominal variables, the subscript F refers to the foreign country and a star means that they are expressed in the foreign currency.

[15]Because of the low of one price, $\frac{P_t}{P_{o,t}} = \frac{P^*_t}{P^*_{o,t}}$.

Asset market equilibrium

Under the two assumptions that asset markets are complete and that the low of one price holds, the equilibrium condition implies that $C_t = C_t^* \ \ \forall\, t$.

Equilibrium in the goods market

Like in CGG, goods market clearing conditions imply that:

$$P_{H,t}Y_t = P_t C_t \qquad P^*_{F,t}Y^*_t = P^*_t C^*_t \tag{3.26}$$

Therefore,

$$C_t = \kappa Y_t^n (Y_t^*)^{1-n} \tag{3.27}$$

where the aggregate output in equilibrium is:

$$Y_t = \frac{A_t N_t^{\alpha} O_{H,t}^{1-\alpha}}{Z_t} \tag{3.28}$$

with $Z_t = \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\theta_p} dj$.

Now that we have all the first order and the market clearing conditions, it is possible to study the dynamics of the model both in the case of no nominal rigidities (section 3.4.5) and under sticky prices and wages (section 3.4.6).

3.4.5 Flexible prices and wages

Let us first study the case in which prices and wages are perfectly flexible in both countries. Using equations (3.8), (3.15), (3.19), (3.26), (3.27) and (3.28)[16], it is possible to derive the following expression for the natural level of output of the home country:

[16] In the flexible price equilibrium $Z_t = 1$.

$$\overline{Y}_t = \alpha^{A_1}\left(\frac{1-\alpha}{\alpha}\right)^{A_2}\kappa^{A_3}[1-\Phi_p]^{A_4}[1-\Phi_w]^{A_5}A_t^{A_6}\left(\frac{\overline{P_{o,t}}}{P_t}\right)^{-A_7}(\overline{Y}^*_t)^{A_8} \tag{3.29}$$

where:

$$A_1 = \frac{1+\varphi(1-\alpha)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]} \qquad A_2 = \frac{(1-\alpha)(1+\varphi)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]}$$

$$A_3 = \frac{1+\varphi(1-\alpha)-\alpha\sigma}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]} \qquad A_4 = \frac{1+\varphi(1-\alpha)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]}$$

$$A_5 = \frac{\alpha}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]} \qquad A_6 = \frac{(1+\varphi)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]}$$

$$A_7 = \frac{(1+\varphi)(1-\alpha)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]} \qquad A_8 = \frac{(1-n)[1+\varphi(1-\alpha)-\alpha\sigma]}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]}$$

Doing the same for the foreign country and using the clearing condition for the oil market (3.25), the equilibrium oil price must satisfies:

$$\frac{\overline{P_{o,t}}}{P_t} = \left[\frac{1}{O^s_t}\right]^{\frac{1+\varphi(1-\alpha)}{\alpha}}\left[\frac{1-\alpha}{\alpha}\right]\left[\frac{1}{1-\Phi_w}\right]\left[\kappa\overline{Y}^n_t(\overline{Y}^*)^{1-n}\right]^{\sigma}$$
$$\left[n\left[\overline{Y}_t A_t^{-1}\right]^{\frac{1+\varphi}{1+\varphi(1-\alpha)}} + (1-n)\left[\overline{Y}^*_t(A^*_t)^{-1}\right]^{\frac{1+\varphi}{1+\varphi(1-\alpha)}}\right]^{\frac{1+\varphi(1-\alpha)}{\alpha}} \tag{3.30}$$

Note that, when $\alpha = 1$, $A_2 = A_7 = 0$ and (3.29) simplifies to the standard:

$$\overline{Y}_t = \left[\kappa^{1-\sigma}[1-\Phi_p][1-\Phi_w]A_t^{1+\varphi}(\overline{Y}^*_t)^{(1-n)(1-\sigma)}\right]^{\frac{1}{1+\varphi-n(1-\sigma)}} \tag{3.31}$$

In this case, when $\sigma = 1$ the natural level of output in (3.31) does not depend on the foreign output. In the more general case, substituting (3.30) into (3.29), we obtain the natural level of output of the home country in function of A_t, ξ_t, A^*_t and $\overline{Y}^*_t$. It is possible to show numerically that even in this more general case the natural level of output is not affected by fluctuations in the foreign variables when $\sigma = 1$.

3.4.6 Sticky prices and wages

In this section we come back to the case where prices and wages are sticky in both countries. Using the log-linearized version of the equilibrium conditions in section 3.4.4 and of the first order conditions derived in sections 3.4.1, 3.4.2 and 3.4.3, we can derive the New Keynesian Phillips Curve (NKPC) from equation (3.18)[17]:

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda \left[A\widehat{\mu}_{w,t} + B(y_t - \overline{y}_t) + C\widehat{\mu}^*_{w,t} + D(y^*_t - \overline{y}^*_t)\right] \tag{3.32}$$

where

$$\begin{aligned} A &\equiv \frac{\alpha + (1-\alpha)n(1+\varphi)}{1+\varphi(1-\alpha)} \quad & B &\equiv \left[\sigma n + 1 - n + \varphi\frac{\alpha}{1+\varphi(1-\alpha)} + n(1+\varphi)\frac{1+\varphi(1-\alpha)-\alpha}{\alpha[1+\varphi(1-\alpha)]}\right] \\ C &\equiv \frac{(1+\varphi)(1-\alpha)(1-n)}{1+\varphi(1-\alpha)} \quad & D &\equiv \frac{(1-\alpha)(1+\varphi)^2(1-n)}{\alpha[1+\varphi(1-\alpha)]} \end{aligned} \tag{3.33}$$

and $\overline{y}_t$ and $\overline{y}^*_t$ represent, respectively, the log of the level of output in absence of nominal rigidities in the home and foreign country. $\widehat{\mu}^*_{w,t}$ represents the log-deviation of the wage mark-up from its frictionless level, in the foreign country.

It is useful to study how the NKPC becomes in some special cases.

No oil used in production, i.e. $\alpha = 1$

In this case, $C = D = 0$, $A = 1$ and $B = \sigma n + 1 - n + \varphi$, i.e. we are back to a standard NKPC with sticky wages. Because of the presence of sticky wages, the monetary authority faces a trade of between stabilizing output gap and stabilizing inflation.

[17] For the complete derivation see Appendix B.1

General case

When $\alpha < 1$, i.e. when oil is used in the production function, the Phillips Curve of the home country is function also of the foreign output gap and of the foreign wage mark-up fluctuations. Therefore, the new assumption on the production process has amplified the *open economy dimension* of the model. The reason for this is simple. Even if, when solving their optimization decisions, foreign producers take home variables and oil price as exogenously given, in equilibrium their production decisions affect oil price through their impact on world oil demand. Therefore, through their impact on world oil price, foreign producers influence home marginal costs. Specifically, when foreign output is above its natural level, foreign oil demand is also going to be above the optimal level and this creates an upward pressure on oil price. Also, when the average wage markup charged by foreign workers is above the one charged under flexible wages, there is going to be a partial substitution between labour and oil in the production process and this will also generate an upward pressure on the oil price.

How much close we are to the standard case depends both on α and n. The role played by α is clear. As α approaches to 1, the role of oil in the production process approaches to 0, therefore we are closing this channel and going back to the standard model. On the other hand, as n approaches 1, the foreign country becomes small and, therefore, it is unable to affect the oil price that is determined at the world level. As a consequence, no matter how big can be the role played by oil in the production process (i.e. no matter how much α can be close to zero), since the oil price will not be affected in a significant way by foreign variables, this new channel will not play an important role and C and D will approach to 0.

In the next section we will use impulse response functions to analyse the different transmission mechanism implied by a supply versus a demand shock.

3.5 Demand vs Supply Shock: Impulse Response Analysis

3.5.1 Baseline Calibration

The two countries are assumed to be perfectly symmetric. They also have the same size, i.e. $n = 0.5$. Most of the parameters have been set following Galí and Monacelli (2005).

Consumer

The discount factor β is set equal to 0.99, implying a riskless annual return of around 4%. The coefficient of relative risk aversion σ is set to 1, implying log utility in consumption. $\varphi = 3$ so that the labour supply elasticity is 1/3. $\theta_w = 6$ implies a wage markup of 1.2. Finally, $\xi_w = 0.75$ i.e. nominal wages adjust, on average, once a year.

Firm

Like for workers, $\theta_p = 0.6$ and $\xi_p = 0.75$. The share of oil in the production α is set equal to 0.05.

Fiscal subsidies

The fiscal authority sets the subsidies τ_w and τ_p such that the flexible (prices and wages) equilibrium is efficient from the single country point of view.

Monetary Policy

It is assumed that the monetary authorities in both countries follow an interest rate rule targeting CPI inflation with a coefficient of 1.5.

Exogenous Shocks

Two kind of shocks are considered. A negative shock to oil supply (exemplifying the oil shocks of the 70s) and a positive shock to foreign productivity (aimed at capturing a demand shock). The foreign productivity process is assumed to be very persistent with $\rho_{A*} = 0.999$. On the contrary oil supply is assumed to be much less persistent with $\rho_o = 0.5$. When studying the impulse responses to a foreign productivity shock we assume $corr_{A,A*} = 0$ in order to be able to disentangle the impact of foreign pressure on oil demand alone.

3.5.2 Demand vs Supply Shock

Two experiments are conducted. The first one is to simulate the model under an oil supply shock that generates an increase of 100% in the real price of oil and that dies off very fast (the correlation coefficient of the process for the oil supply is indeed $\rho_o = 0.5$). Since the increase in the 70s of the oil price was always happening in a few quarters, this experiment is meant to replicate such circumstances. Figure 3.6 reports the impulse responses of the real price of oil plus the following home variables: CPI inflation, real output, domestic inflation, real wage and wage inflation. This shock reproduces in the model an episode of stagflation like the one observed in the 70s with a contraction in output accompanied by a rise in inflation (measured both in terms of domestic inflation and CPI inflation), a rise in wage inflation and a contraction of real wages. This shock is symmetric for both countries therefore the impulse response functions for the foreign country are exactly the same as for the home country. The reason behind those dynamics is that such a shock increases production costs in both countries, therefore it fuels inflation, both in terms of domestically produced goods and with respect to goods produced abroad. This decreases real wages and contracts total output. More in detail, the supply shock generates a reduction in the home output of 0.9%, consistent with a reduction in the yearly growth rate of GDP of around 3.6%. Inflation (measured both in terms of CPI inflation and domestic inflation) increases by 0.6%, implying an increase in the yearly rate of 2.4%. This generates a decrease in real wages of 0.4% i.e., a reduction in one year of 1.6% accompanied by an yearly increase in wage inflation of around 0.6%. The direction in the changes of those variables is consistent with the one observed in the 70s even if the magnitude is lower than the one reported in table 3.2. It is important to note however that, given that the supply side of the oil market is not explicitly modelled, while conducting this experiment it is not possible to evaluate whether the quantity reduction in the oil supply needed to deliver the 100% increase in the oil price is consistent with what happened in reality. This problem is common to all papers mentioned in the literature review which studies the transmission of oil price shocks considering an exogenous process for the oil price. In this model a more careful experiment can instead be conducted when studying a demand shock.

In the second experiment the idea is to approximate the increase in demand driven by the growth process involving Asian countries. As a first approximation, we calibrate the shock to the foreign technology in order to deliver an increase in foreign output (on impact) of 3%. This is approximately consistent with the quarterly growth rate experienced by China between 2001 and 2006. The results are shown in figure 3.7. We are aware the the correct experiment would be to consider an increase in the growth rate of the foreign country. As a first approximation, we set the autocorrelation coefficient for the technology process close to one.

Since the foreign country is more productive, foreign produced goods become cheaper. Therefore, there will be an increase in the demand for those goods from foreign consumers (that are now richer) but also from home consumers. At the same time also the demand for home produced goods will increase because of the income effect affecting foreign consumers. As a consequence, home output is going to increase. The increase in production in both countries drives up world oil demand and, therefore, the oil price. This increases domestic inflation in the home country because of the increase in the production costs (the home country is producing more without being more productive). Home CPI inflation instead decreases because now home consumers are importing goods from abroad at a cheaper price[18]. This explain how we can be experiencing a reduction in CPI inflation and an increase in domestic inflation and output together with an increase in the oil price. Real wages increases because of the reduction in CPI. The direction of the change in those variables is consistent with the one experienced by the U.S. variables in the 2000s (see table 3.6). The only difference between the model and the data is in the behaviour of wage inflation. While wage inflation is decreasing in the data, it is increasing in the model. Two things are worth noticing. The first one is that even if wage inflation is increasing under the demand shock, this increase is lower then the one experienced under a supply shock. The second is that the direction of the change in wage inflation depends very much on the persistence of the technology shock. When $\rho_{A*} = 0.9$, wage inflation decrease after a positive shock to foreign technology. Quantitatively, the shock delivers an increase in the real oil price of 1.5% in one quarter. Since China experienced this growth rate for around 24 quarters, it can explain an increase in oil price of around 40%. This is a reasonable results given that other shocks are affecting the world economy at the same time. The movements in the other variables are of the right sign but the magnitude is bigger than the one observed in the data, especially for what concerns the home output. One possible explanation for this is that the model has been solved under the assumption of no home bias. Removing this assumption would capture the fact that most of China consumption is still on home produced

[18]Note that this difference in the behaviour of CPI inflation and domestic inflation is consistent with the one experienced by the U.S. in correspondence of the last oil price increase (see table 3.2).

goods. This would decrease the impact of the foreign productivity shock on home output. It would also allow to study how much the dynamics of imports and exports in the model do match the data for the U.S. and China. As last remark it may be worth noticing that, under the present specification of the model, considering the case in which the monetary policy in the foreign country keeps the nominal exchange rate constant does not affect the results.

3.6 Conclusions

The paper started asking the question of how is it possible that, despite the same magnitude in the increase in the price of oil, the 2000s appear to be so different from the 70s, with a positive output growth, a low (even decreasing) CPI inflation and increasing real wages. An explanation based on different shocks hitting the economy in the two periods, relating in particular the current behaviour of U.S. variables and oil price with the growth in China has been provided. In particular, using a two-country model where the price of oil is determined endogenously, two kind of shocks have been considered: a negative shock to oil supply and a positive shock to foreign country productivity. The model, despite its simplicity, is able to generate changes in the relevant variables under the two types of shocks that are consistent with the ones observed in the data.

Table 3.1: **% Change in the Real Oil Price During Each Oil Shock Period**

Q2:73 - Q1:74	Q4:78 - Q2:80	Q4:98 - Q4:00	Q4:01 - Q3:05
97%	79%	85%	103%

Table 3.2: **% Change between 4 quarters after and 4 quarters before the oil shock**

	Q1:74	Q3:79	Q3:99	Q1:03
CPI Inflation	3.29	3.26	1.15	-0.35
GDP Defl. Inflation	3.44	0.46	0.63	0.50
Real GDP Growth	-6.02	-3.29	0.41	1.75
Real Wage	-2.26	-4.76	0.69	0.67
Wage Inflation	3.1753	-0.8838	0.4428	-0.9325

Table 3.3: **% Change between 8 quarters after and 8 quarters before the oil shock**

	Q1:74	Q3:79	Q3:99	Q1:03
CPI Inflation	3.5680	2.9422	1.4251	0.5428
GDP Defl. Inflation	3.1880	1.5933	1.0106	0.5794
Real GDP Growth	-5.0952	-3.1710	-1.3663	2.4373
Real Wage	-1.7812	-5.4471	0.7128	1.6178
Wage Inflation	1.2753	0.7356	0.3578	-0.6904

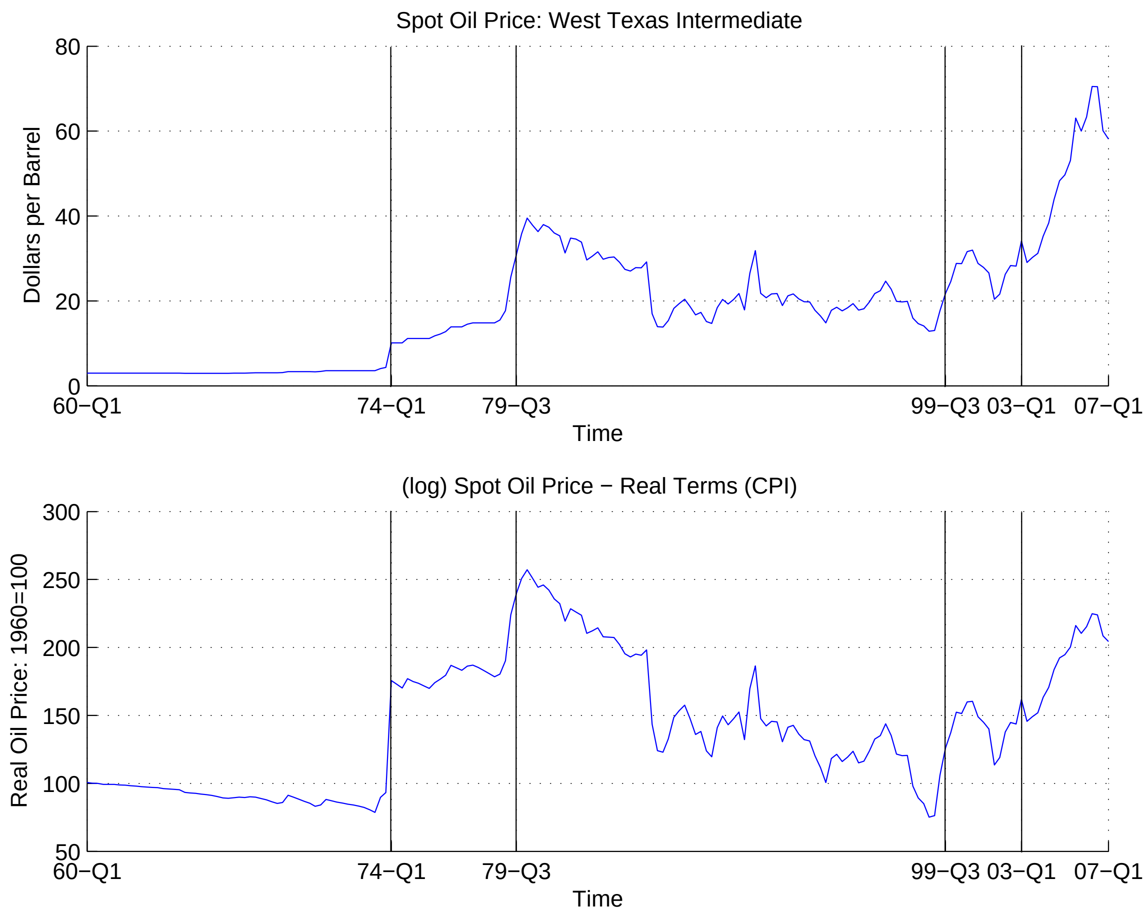

Figure 3.1: Oil Price - Nominal and Real - Q1:1960 - Q1:2007

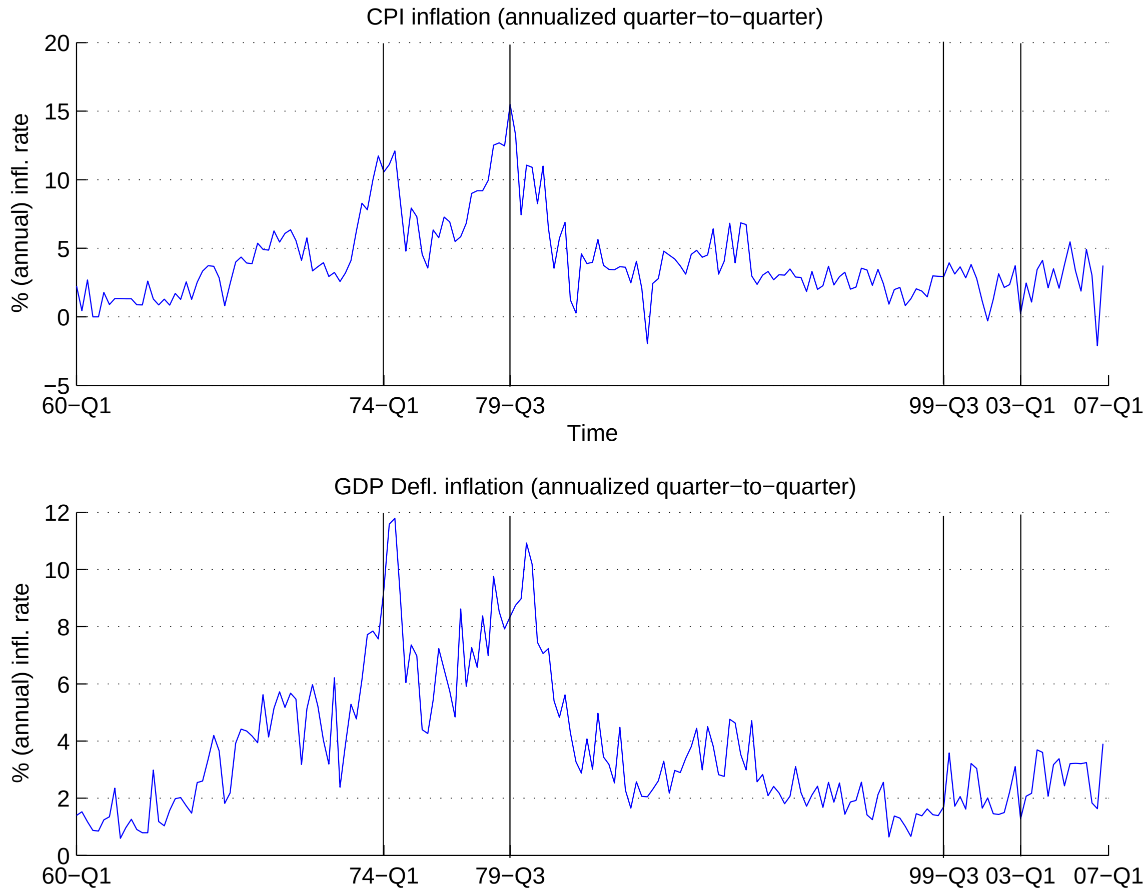

Figure 3.2: CPI and GDP Deflator Inflation Rates - Q1:1960 - Q1:2007

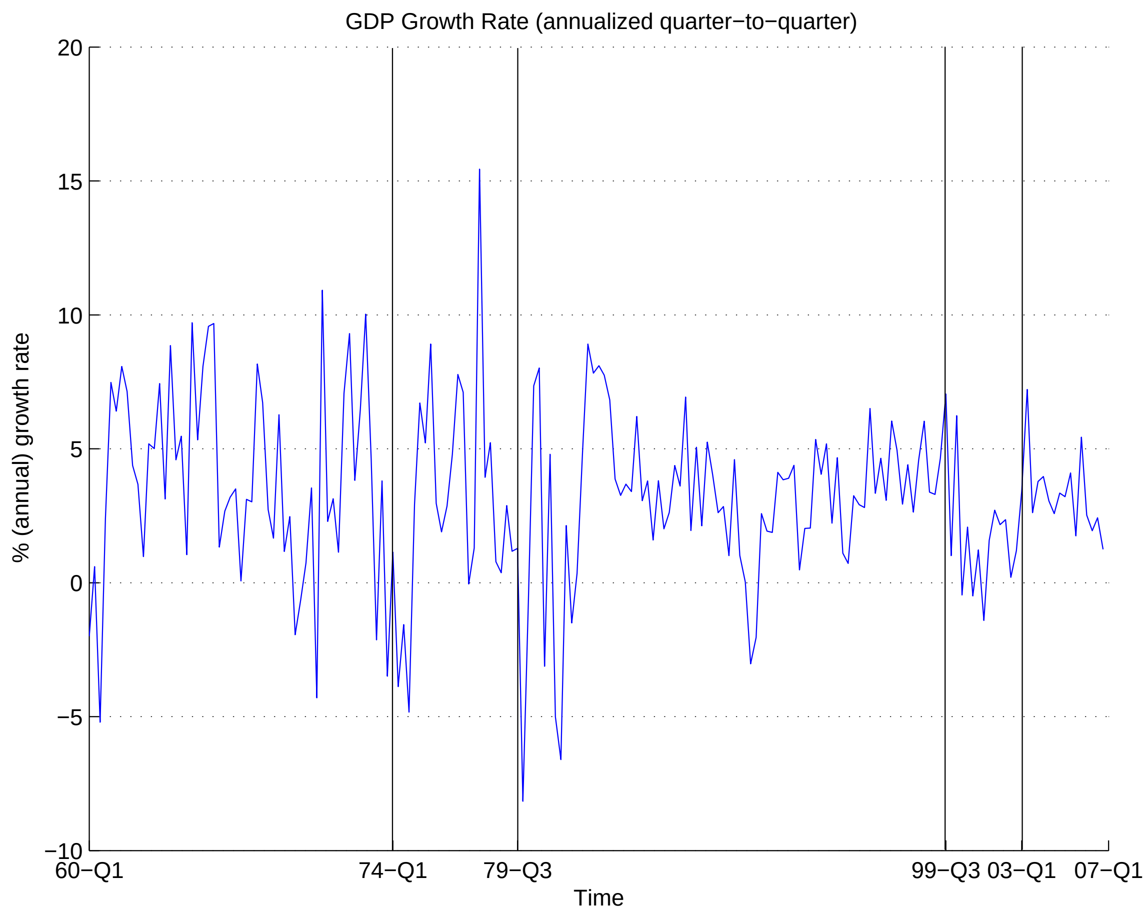

Figure 3.3: Real GDP Growth Rate - Q1:1960 - Q1:2007

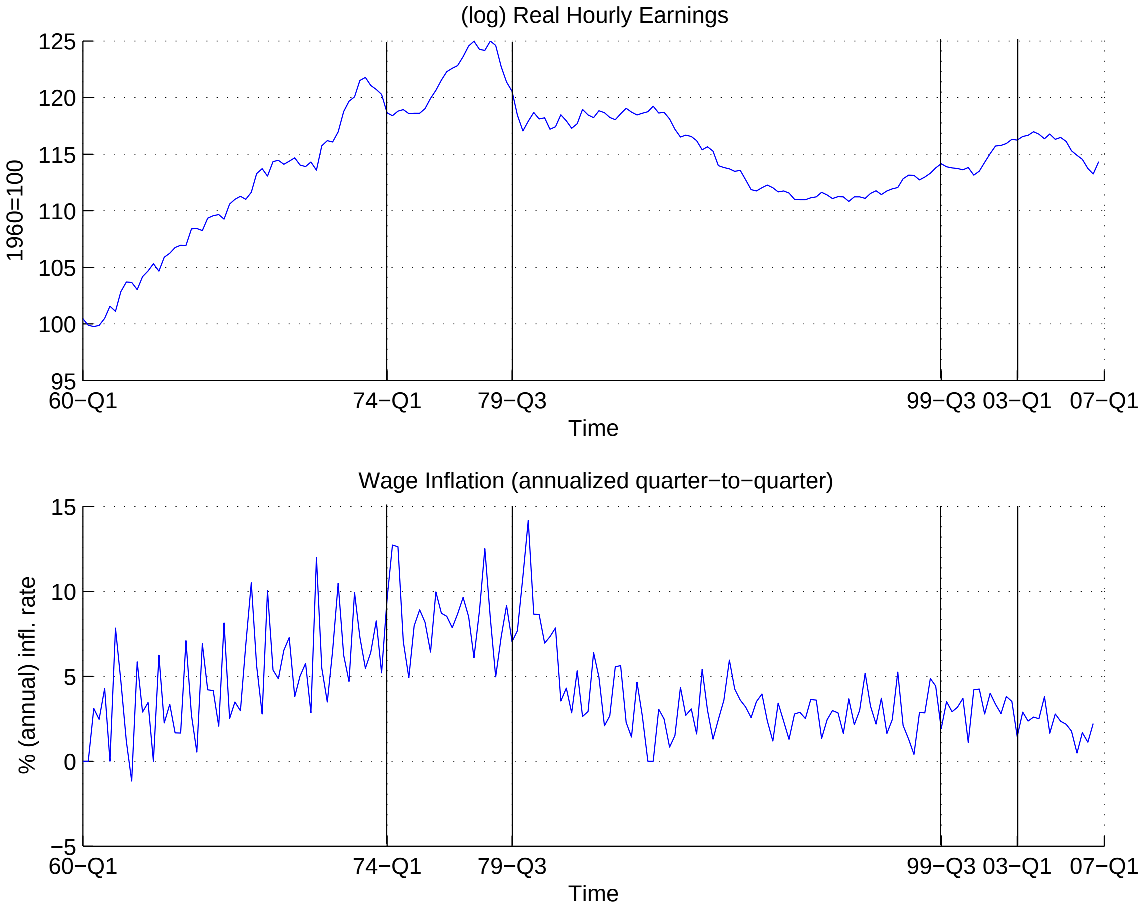

Figure 3.4: Real Wage and Wage Inflation - Q1:1960 - Q1:2007

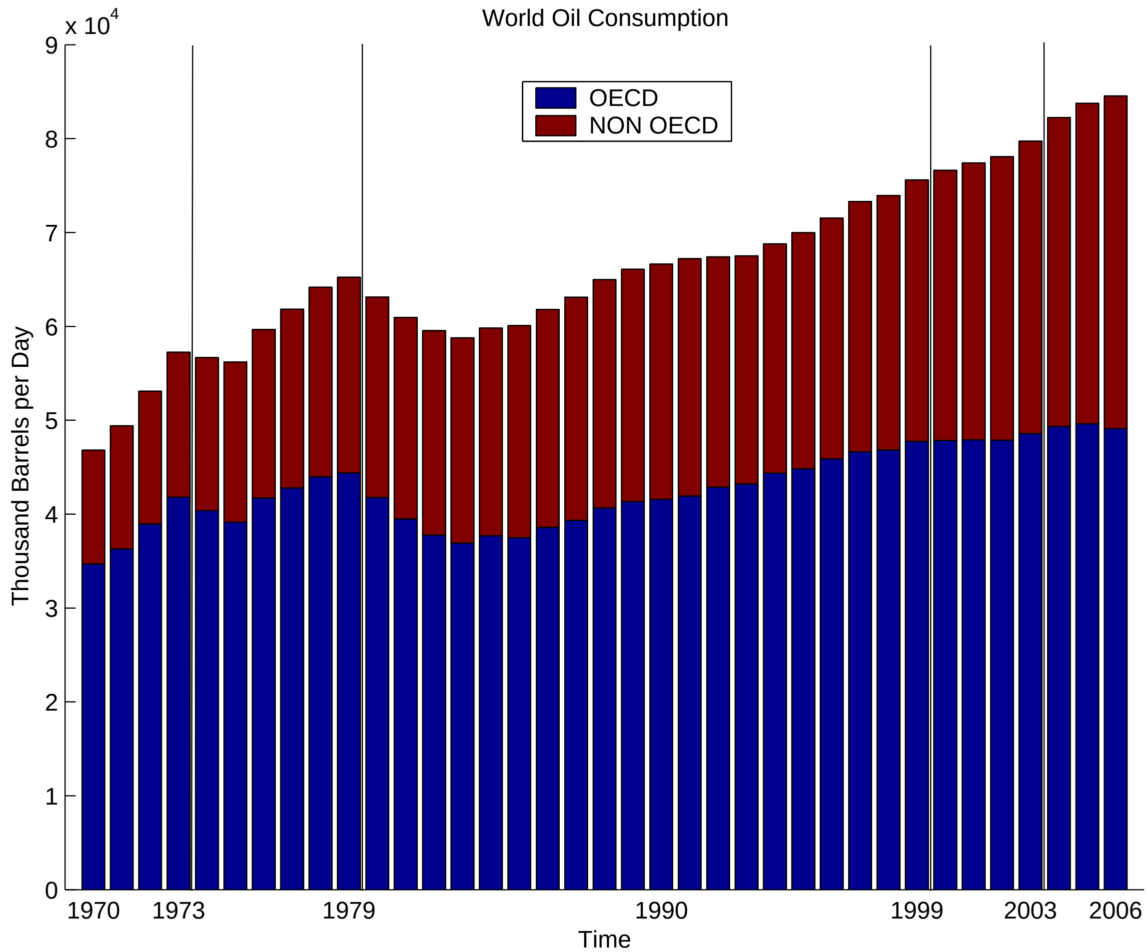

Figure 3.5: World Oil Consumption - Yearly Average - 1970 - 2006

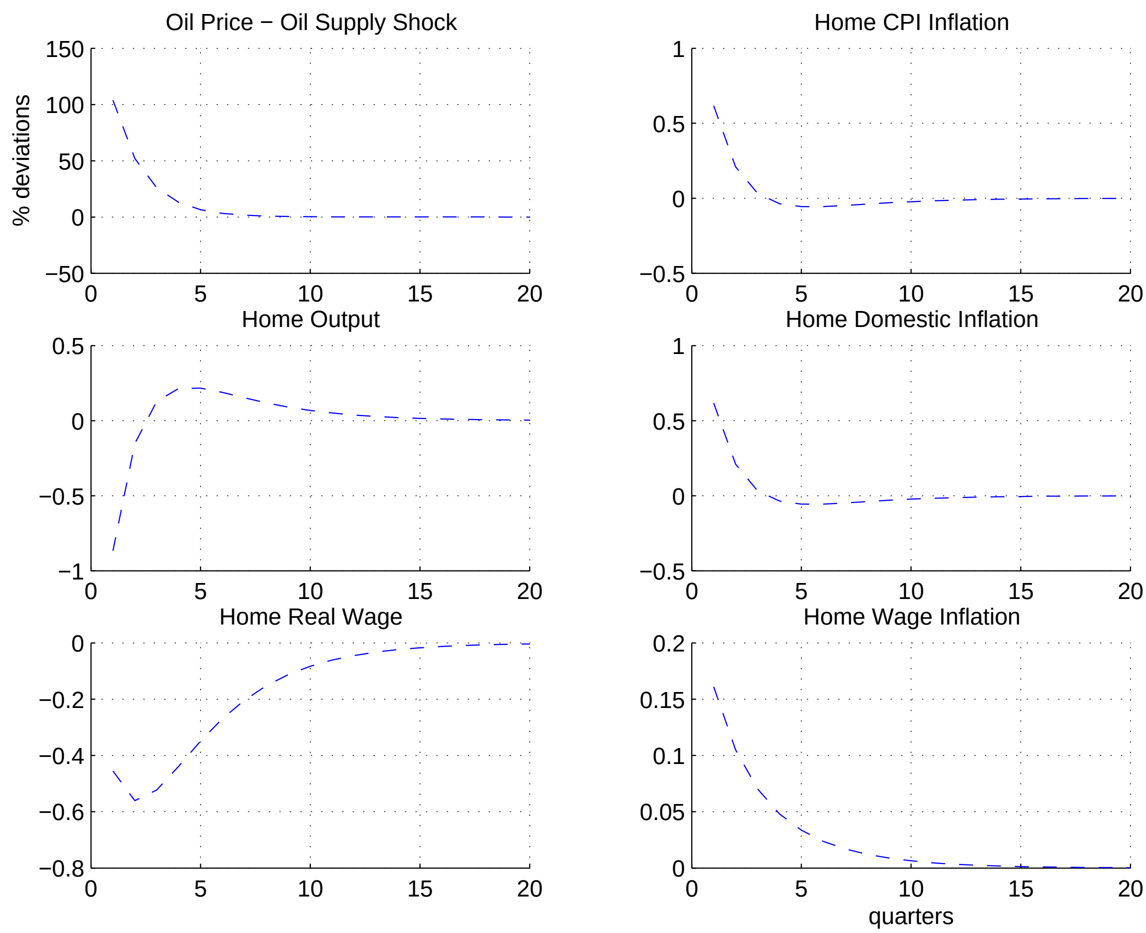

Figure 3.6: Impulse Responses: Oil Supply Shock

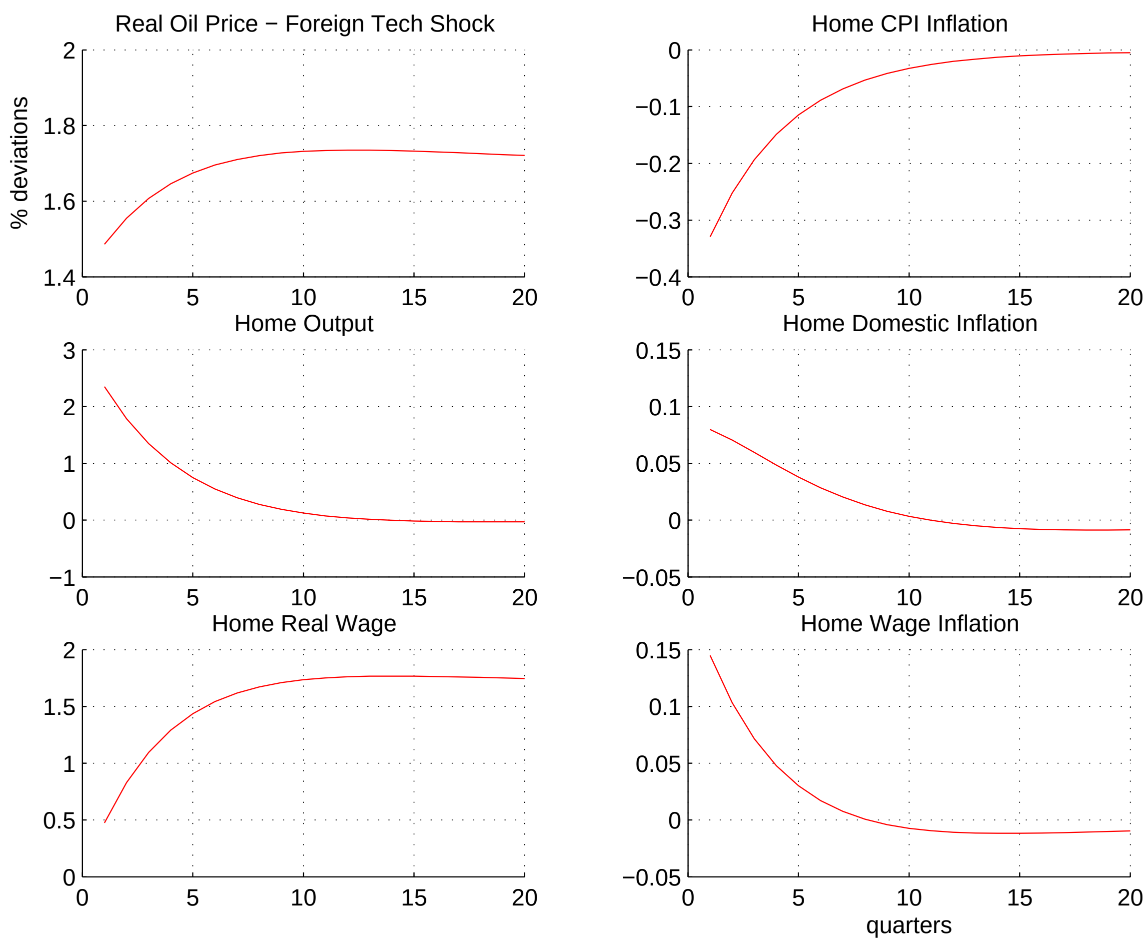

Figure 3.7: Impulse Responses: Foreign Technology Shock

Appendix A

Chapter 1

A.1 Derivation of $\widehat{mc}_t$

Making use of some of the equilibrium conditions defined in (1.3.3), the real marginal cost can be written as:

$$\begin{aligned} mc_t &= w_t - p_{H,t} - a_t \\ &= mrs_t + log(\mu_{w,t}) + p_t - p_{H,t} - a_t \\ &= \sigma * y_t^* + (1-\alpha)s_t + \varphi(y_t - a_t) + \alpha * s_t - a_t + log(\mu_{w,t}) \\ &= (\sigma - \sigma_\alpha)y_t^* + (\sigma_\alpha + \varphi)y_t - (1+\varphi)a_t + log(\mu_{w,t}) \end{aligned} \tag{A.1}$$

where $\mu_{w,t}$ represents the actual mark up charged in each period[1]. From equation (A.1) we can express the level of output as:

$$y_t = \frac{mc_t}{\sigma_\alpha + \varphi} - \frac{\sigma - \sigma_\alpha}{\sigma_\alpha + \varphi} y_t^* + \frac{1+\varphi}{\sigma_\alpha + \varphi} a_t - \frac{log(\mu_{w,t})}{\sigma_\alpha + \varphi} \tag{A.2}$$

Let's define $\bar{y}_t$ the natural level of output, i.e. the level of output in absence of nominal

[1]Note that with the presence of taxes that exactly offset the monopoly distortions, the wedge between the real wage and the mrs_t is do only to the presence of stickiness, whereas when $\Phi_w > 0$ then $\mu_{w,t}$ reflects both the presence of stickiness and the presence of monopoly power.

rigidities:

$$\bar{y}_t = \frac{mc}{\sigma_\alpha + \varphi} - \frac{\sigma - \sigma_\alpha}{\sigma_\alpha + \varphi} y_t^* + \frac{1+\varphi}{\sigma_\alpha + \varphi} a_t + \frac{log(1-\Phi_w)}{\sigma_\alpha + \varphi} \tag{A.3}$$

Then,

$$y_t - \bar{y}_t = \frac{\widehat{mc}_t}{\sigma_\alpha + \varphi} - \frac{\widehat{\mu}_{w,t}}{\sigma_\alpha + \varphi} \tag{A.4}$$

that is exactly equation (1.37).

A.2 Derivation of the loss function

A.2.1 Step 1: Derivation of $W_t - \overline{W}$

All the results in this section are derived under the assumption $\sigma = \eta = 1$. Under this assumption the relations defined in (1.3.3) hold exactly and it is possible to derive a second order approximation of the utility function using first order approximation of the structural equations.

From now on all the variables of the type $\widehat{a}_t$ represent log deviations from the steady state.

We will substitute the following expression of the second order derivative: $V_{NN} = \varphi * V_N N^{-1}$. We will also use the fact that:

$$\frac{X_t - \overline{X}}{\overline{X}} = \widehat{x}_t + \frac{1}{2}\widehat{x}_t^2 + o(\|a\|^3) \tag{A.5}$$

The first step is to compute a second order approximation around the steady state of (1.42).

Up to a second order approximation it is true that:

$$U(C_t) =$$
$$+U(\overline{C}) + \overline{U}_C(C_t - \overline{C}) + \frac{1}{2}\overline{U}_{CC}(C_t - \overline{C})^2 + o(\|a\|^3) \tag{A.6}$$

Using (A.5) and the relations between consumption and output defined in (1.3.3)the previous equation becomes:

$$\begin{aligned} U(C_t) - U(\overline{C}) &= \widehat{c}_t + o(\|a\|^3) \\ &= (1-\alpha)\widehat{y}_t + o(\|a\|^3) \end{aligned} \tag{A.7}$$

In an analogous way it's true that:

$$E_h V(N_t(h)) =$$
$$V(\overline{N}) + E_h[\overline{V}_N(N_t - \overline{N})] + \frac{1}{2}E_h[\overline{V}_{NN}(N_t - \overline{N})^2] + o(\|a\|^3) \tag{A.8}$$

that using (A.5) and the relation between first order and second order derivatives leads to:

$$E_h[V(N_t(h)] =$$
$$V(\overline{N}) + \overline{V}_N\overline{N}E_h\left[\widehat{n}_t(h) + \frac{1+\varphi}{2}\widehat{n}_t^2(h)\right] + o(\|a\|^3) \tag{A.9}$$

Combining (A.7) and (A.9) leads to:

$$W_t - \overline{W} =$$
$$(1-\alpha)\widehat{y}_t + \overline{V}_N\overline{N}E_h[\widehat{n}_t(h) + \frac{1+\varphi}{2}\widehat{n}_t^2(h)] + o(\|a\|^3) \tag{A.10}$$

The second step is to compute the approximation of the two expected values.

A.2.2 Step 2: Derivation of $E_h[\widehat{n}_t(h)]$ and $E_h[\widehat{n}_t^2(h)]$

Since in general, for $A = \left[\int_0^1 A(i)^{\phi} di\right]^{\frac{1}{\phi}}$, it's true that[2] $\widehat{a}_t = E_i[\widehat{a}(i)] + \frac{1}{2}\phi * Var_i[\widehat{a}(i)] + o(\|a\|^3)$ then, given the way in which aggregate labour has been defined, it is possible to write:

$$\widehat{n}_t = E_h[\widehat{n}_t(h)] + \frac{1}{2}\frac{\theta_w - 1}{\theta_w} Var_h[\widehat{n}_t(h)] + o(\|a\|^3) \quad \text{(A.11)}$$

Following Erceg et al. (2000), it is useful to write $\widehat{n}_t$ in function of the aggregate demand of labour by firms $N_t = \int_0^1 N_t(j)dj$:

$$\widehat{n}_t = E_j[\widehat{n}_t(j)] + \frac{1}{2} Var_j[\widehat{n}_t(j)] + o(\|a\|^3) \quad \text{(A.12)}$$

Clearly, since $\widehat{y}_t(j) = a_t + \widehat{n}_t(j)$ then, $Var_j[\widehat{n}_t(j)] = Var_j[\widehat{y}_t(j)]$ and $E_j[\widehat{n}_t(j)] = E_j[\widehat{y}_t(j)] - a_t$. Also, given the expression for aggregate output, $E_j[\widehat{y}_t(j)] = \widehat{y}_t - \frac{1}{2}\frac{\theta_p - 1}{\theta_p} Var_j[\widehat{y}_t(j)] + o(\|a\|^3)$ therefore, we can write:

$$\begin{aligned} E_h[\widehat{n}_t(h)] &= \widehat{n}_t - \frac{1}{2}\frac{\theta_w - 1}{\theta_w} Var_h[\widehat{n}_t(h)] + o(\|a\|^3) \\ &= E_j[\widehat{y}_t(j)] - a_t + \frac{1}{2} Var_j[\widehat{y}_t(j)] - \frac{1}{2}\frac{\theta_w - 1}{\theta_w} Var_h[\widehat{n}_t(h)] + o(\|a\|^3) \\ &= \widehat{y}_t - a_t + \frac{1}{2\theta_p} Var_j[\widehat{y}_t(j)] - \frac{1}{2}\frac{\theta_w - 1}{\theta_w} Var_h[\widehat{n}_t(h)] + o(\|a\|^3) \quad \text{(A.13)} \end{aligned}$$

For the other expected value:

$$E_h[\widehat{n}_t^2(h)] = Var_h[\widehat{n}_t(h)] + [E_h[\widehat{n}_t(h)]]^2 \quad \text{(A.14)}$$

A.2.3 Step 3: Derivation of $W_t - W_t^n$

Having chosen optimally τ_p and τ_w, the following holds $-\overline{V}_N \overline{N} = (1 - \alpha)$. Then, using this relation and substituting (A.13) and (A.14) into (A.10), the second order

[2] The reference for the results in this section is Erceg et al. (2000).

approximation of the welfare function around the steady state becomes:

$$
\begin{aligned}
W_t - \overline{W} = &\\
&(1-\alpha)a_t - \frac{(1-\alpha)}{2\theta_p} Var_j[\widehat{y}_t(j)] - \frac{(1-\alpha)(1+\varphi\theta_w)}{2\theta_w} Var_h[\widehat{n}_t(h)] + \\
&- \frac{(1-\alpha)(1+\varphi)}{2}(\widehat{y}_t - a_t)^2 + o(\|a\|^3)
\end{aligned} \tag{A.15}
$$

Computing the approximation around the steady state of the welfare function in absence of nominal rigidities leads to[3]:

$$
\begin{aligned}
W_t^n - \overline{W} = &\\
&(1-\alpha)a_t - \frac{(1-\alpha)(1+\varphi)}{2}(\widehat{y}_t^n - a_t)^2 + o(\|a\|^3)
\end{aligned} \tag{A.16}
$$

Consequently,

$$
\begin{aligned}
W_t - W_t^n = &\\
&- \frac{(1-\alpha)(1+\varphi)}{2}(\widehat{y}_t^2 - (\widehat{y}_t^n)^2) + (1-\alpha)(1+\varphi)(\widehat{y}_t - \widehat{y}_t^n)a_t + \\
&- \frac{(1-\alpha)}{2\theta_p} Var_j[\widehat{y}_t(j)] - \frac{(1-\alpha)(1+\varphi\theta_w)}{2\theta_w} Var_h[\widehat{n}_t(h)] + o(\|a\|^3)
\end{aligned} \tag{A.17}
$$

From the log-linearization of equation (1.40), $a_t = \widehat{y}_t^n$.

From (A.17):

$$
\begin{aligned}
W \equiv \sum_{t=0}^{\infty} \beta^t (W_t - W_t^n) = &\\
&- \frac{1-\alpha}{2} \sum_{t=0}^{\infty} \beta^t \left[(1+\varphi)x_t^2 + \frac{1}{\theta_p} Var_j\left[\widehat{y}_t(j)\right] + \frac{1+\varphi\theta_w}{\theta_w} Var_h\left[\widehat{n}_t(h)\right] \right]
\end{aligned} \tag{A.18}
$$

[3]With flexible prices and wages there are no differences across workers and firms so $Var_j = Var_h = 0$

where $x_t = \widehat{y}_t - \widehat{y}_t^n = y_t - y_t^n$. As proved by Woodford (2001),

$$\sum_{t=0}^{\infty} \frac{\beta^t}{\theta_p} Var_j\left[\widehat{y}_t(j)\right] = \frac{\theta_p}{\lambda} \sum_{t=0}^{\infty} \beta^t \pi_{H,t}^2 \tag{A.19}$$

It remains to study $Var_h[\widehat{n}_t(h)]$. Let's first write the log linear labour demand faced by each household:

$$\widehat{n}_t(h) = -\theta_w \log(W_t(h)) + \theta_w \log(W_t) + \widehat{n}_t + o(\|a\|^2) \tag{A.20}$$

consequently:

$$Var_h[\widehat{n}_t(h)] = \theta_w^2 Var_h[w_t(h)] \tag{A.21}$$

with $w_t(h) = \log(W_t(h))$.

The next step is to compute $Var_h[w_t(h)]$.

A.2.4 Step 4: Derivation of $Var_h[w_t(h)]$

First it is useful to decompose the variance as[4]:

$$\begin{aligned} Var_h[w_t(h)] &= E_h[w_t(h) - E_h w_t(h)]^2 \\ &= \xi_w E_h[w_{t-1}(h) - E_h w_t(h)]^2 \\ &\quad +(1-\xi_w)[\widetilde{w}_t - E_h w_t(h)]^2 \end{aligned} \tag{A.22}$$

Using the log-linearized expression for the aggregate wage and the result by Erceg et al. (2000) that $w_t - E_h w_t(h) = o(\|a\|^2)$ then,

[4]In general, if X assumes value X_1 with probability α and X_2 with probability $(1-\alpha)$, then $E(X^2) = \alpha * X_1^2 + (1-\alpha)X_2^2$, but the fraction of workers that can not reoptimise in t will all have a different wage, that's why, like in Erceg et al. (2000), we need to take expectations again.

$$
\begin{aligned}
E_h[w_{t-1}(h) - E_h w_t(h)]^2 &= E_h[w_{t-1}(h) - w_t + o(\|a\|^2)]^2 \\
&= E_h[w_{t-1}(h) - E_h w_{t-1}(h) - \pi_{w,t} + o(\|a\|^2)]^2 \\
&= Var_h w_{t-1} + \pi_{w,t}^2 + o(\|a\|^3) \qquad \text{(A.23)}
\end{aligned}
$$

With the same arguments we have:

$$
\begin{aligned}
[\widetilde{w}_t - E_h w_t(h)]^2 &= [\widetilde{w}_t - w_t]^2 + o(\|a\|^3) \\
&= \left[\frac{\xi_w}{1-\xi_w}\pi_{w,t}\right]^2 + o(\|a\|^3) \qquad \text{(A.24)}
\end{aligned}
$$

Substituting (A.23) and (A.24) into (A.22) we can write:

$$
Var_h[w_t(h)] = \xi_w Var_h w_{t-1}(h) + \frac{\xi_w}{1-\xi_w}\pi_{w,t}^2 \qquad \text{(A.25)}
$$

Like in Woodford (2001), we can define $\triangle_t^w = Var_h[w_t(h)]$. Consequently we can rewrite (A.25) as:

$$
\triangle_t^w = \xi_w \triangle_{t-1}^w + \frac{\xi_w}{1-\xi_w}\pi_{w,t}^2 + o(\|a\|^3) \qquad \text{(A.26)}
$$

Iterating backward, the previous equation can be written has:

$$
\triangle_t^w = \xi_w^{t+1}\triangle_{-1}^w + \sum_{s=0}^{t} \xi_w^s \frac{\xi_w}{1-\xi_w}\pi_{w,t-s}^2 + o(\|a\|^3) \qquad \text{(A.27)}
$$

Following Woodford (2001):

$$
\sum_{t=0}^{\infty} \beta^t \triangle_t^w = \frac{\xi_w}{(1-\beta\xi_w)(1-\xi_w)} \sum_{t=0}^{\infty} \beta^t \pi_{w,t}^2 + t.i.p. + o(\|a\|^3) \qquad \text{(A.28)}
$$

A.2.5 Final expression

Combining the results in previous sections:

$$W = -\frac{1-\alpha}{2} \sum_{t=0}^{\infty} \beta^t \left[(1+\varphi) x_t^2 + \frac{\theta_p}{\lambda} \pi_{H,t}^2 + \frac{\theta_w}{\lambda_w} \pi_{w,t}^2 \right] \tag{A.29}$$

Taking unconditional expectation of (A.29) and letting $\beta \rightarrow 1$ the expected welfare loss is:

$$L = -\frac{1-\alpha}{2} \left[(1+\varphi) Var(x_t) + \frac{\theta_p}{\lambda} Var(\pi_{H,t}) + \frac{\theta_w}{\lambda_w} Var(\pi_{w,t}) \right] \tag{A.30}$$

A.3 System of equations fully characterizing the model

With the inclusion of a monetary policy rule the following system of equations fully characterize the model:

$$\alpha s_t = \alpha s_{t-1} + \pi_t - \pi_{H,t} \tag{A.31}$$

$$y_t = c_t + \alpha s_t \tag{A.32}$$

$$\overline{y}_t = \frac{\log(1-\alpha)}{1+\varphi} + a_t \tag{A.33}$$

$$y_t = a_t + n_t \tag{A.34}$$

$$\begin{aligned} \pi_{w,t} &= w_t + \pi_t - w_{t-1} \\ w_t &= \log(W_t / P_t) \end{aligned} \tag{A.35}$$

$$s_t = y_t - y_t^* \tag{A.36}$$

$$x_t = y_t - \overline{y}_t \tag{A.37}$$

$$c_t = -\left[r_t - \rho - E_t \pi_{t+1}\right] + E_t c_{t+1} \tag{A.38}$$

$$\pi_{w,t} = \beta E_t \pi_{w,t+1} - \lambda_w \left[w_t - c_t - \varphi n_t\right] \tag{A.39}$$

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda(1+\varphi)x_t + \lambda \left[w_t - c_t - \varphi n_t\right] \tag{A.40}$$

$$y^*_{t+1} = \rho_y y^*_t + \varepsilon_{y,t}. \tag{A.41}$$

$$a_{t+1} = \rho_a a_t + \varepsilon_{A,t}. \tag{A.42}$$

Appendix B

Chapter 3

B.1 Derivation of $\widehat{mc}_t$

All lower case letters indicate the log of the variables. For a generic variable x_t, $\widehat{x}_t$ represents log deviation from the steady state when there are nominal rigidities, and $\widetilde{x}_t$ stands for log deviation from the steady state when there are no nominal rigidities. $\overline{x}_t$ characterizes the frictionless level of the variables. For simplicity, either both countries faces nominal rigidities or they both operate in a flexible environment.

Writing (3.17) in log-deviation from the steady state, remembering that $w_{h,t} - p_t = \mu_{w,t} + \varphi n_t + \sigma c_t$[1], and using (3.26) together with the fact that $\widehat{x}_t - \widetilde{x}_t = x_t - \overline{x}_t$, we can write:

$$\widehat{mc}_t = \alpha[\widehat{\mu}_{w,t} + \varphi(n_t - \overline{n}_t)] + (\alpha\sigma - 1)(c_t - \overline{c}_t) + \\ + (1-\alpha)\left[\log\left(\frac{P_{o,t}}{P_t}\right) - \overline{\frac{P_{o,t}}{P_t}}\right] + y_t - \overline{y}_t \quad \text{(B.1)}$$

Taking a first order approximation of (3.28) around the steady state and using (3.15), we have:

[1] $\mu_{w,t}$ is the wage mark-up charged each period.

$$\widehat{n}_t = \widehat{y}_t - \alpha a_t - (1-\alpha)[\widehat{\mu}_{w,t} + \varphi \widehat{n}_t - \sigma \widehat{c}_t] + (1-\alpha)\frac{\widehat{P_{o,t}}}{P_t} \tag{B.2}$$

Taking a first order approximation of (3.25), using the fact that $c_t = c_t^*$, considering the fact that the steady state is symmetric across countries, and that also for the foreign country $w_{h,t}^* - p_t^* = \mu_{w,t}^* + \varphi n_t^* + \sigma c_t^*$, we have:

$$\frac{\widehat{P_{o,t}}}{P_t} = -\widehat{\xi}_t + n\widehat{\mu}_{w,t} + (1-n)\widehat{\mu}_{w,t}^* + n(1+\varphi)\widehat{n}_t + (1-n)(1+\varphi)\widehat{n}_t^* + \sigma \widehat{c}_t \tag{B.3}$$

From (3.27) we have that:

$$\widehat{c}_t = n\widehat{y}_t + (1-n)\widehat{y}_t^* \tag{B.4}$$

We can write an expression analogous to (B.2) for the foreign country. Using that equation together with (B.2), (B.3) and (B.4) we can write $\widehat{n}_t$ and $\frac{\widehat{P_{o,t}}}{P_t}$ as function only of the exogenous shocks (a_t,a_t^* and ξ_t), $\widehat{y}_t$, $\widehat{y}_t^*$, $\widehat{\mu}_t$ and $\widehat{\mu}_t^*$:

$$\begin{aligned}\frac{\widehat{P_{o,t}}}{P_t} &= -\frac{1+\varphi(1-\alpha)}{\alpha}\widehat{\xi}_t - \frac{n(1+\varphi)}{\alpha}a_t - \frac{(1-n)(1+\varphi)}{\alpha}a_t^* + \\ &+ \left[\frac{n(1+\varphi)}{\alpha} + \sigma n\right]\widehat{y}_t + \left[\frac{(1-n)(1+\varphi)}{\alpha} + \sigma(1-n)\right]\widehat{y}_t^* + n\widehat{\mu}_{w,t} + (1-n)\widehat{\mu}_{w,t}^*\end{aligned} \tag{B.5}$$

$$\begin{aligned}\widehat{n}_t = &-\frac{1-\alpha}{\alpha}\xi_t + \frac{\alpha + n(1-\alpha)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(\widehat{y}_t - a_t) + \\ &+ \frac{(1-\alpha)(1-n)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(\widehat{y}_t^* - a_t^*) + \frac{(1-n)(1-\alpha)}{1+\varphi(1-\alpha)}(\widehat{\mu}_{w,t}^* - \widehat{\mu}_{w,t})\end{aligned} \tag{B.6}$$

Using the fact that $\widehat{x}_t - \widetilde{x}_t = x_t - \overline{x}_t$, we obtain:

$$\frac{P_{o,t}}{P_t} - \overline{\frac{P_{o,t}}{P_t}} = \left[\frac{n(1+\varphi)}{\alpha} + \sigma n\right](y_t - \overline{y}_t) + \\ + \left[\frac{(1-n)(1+\varphi)}{\alpha} + \sigma(1-n)\right](y_t^* - \overline{y}_t^*) + n\widehat{\mu}_{w,t} + (1-n)\widehat{\mu}_{w,t}^* \quad \text{(B.7)}$$

$$n_t - \overline{n}_t = \frac{\alpha + n(1-\alpha)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(y_t - \overline{y}_t) + \\ + \frac{(1-\alpha)(1-n)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(y_t^* - \overline{y}_t^*) + \frac{(1-n)(1-\alpha)}{1+\varphi(1-\alpha)}(\widehat{\mu}_{w,t}^* - \widehat{\mu}_{w,t}) \quad \text{(B.8)}$$

$$c_t - \overline{c}_t = n(y_t - \overline{y}_t) + (1-n)(y_t^* - \overline{y}_t^*) \quad \text{(B.9)}$$

Substituting equations (B.7), (B.8) and (B.9) into (B.1) we obtain the expression for the log deviation of the real marginal cost that, once substitute into (3.20), gives equation (3.32) in the text.

B.2 Data description

All variables refer to U.S.A. All data are available for the period Q1:1960-Q1:2007 with only exception of oil consumption which is available since 1970.

Nominal Oil Price

Spot Oil Price, West Texas Intermediate, dollars per barrel, quarterly observations constructed from monthly data. Source:http://www.eia.doe.gov/.

Nominal GDP

Gross Domestic Product, seasonally adjusted annual rate, billions of dollars, quarterly observations. Source: FRED, http://research.stlouisfed.org/fred2/.

GDP Deflator

Gross Domestic Product Implicit Price Deflator, seasonally adjusted, quarterly observations, index 2000 = 100. Source: FRED, http://research.stlouisfed.org/fred2/.

Consumer Price Index

Consumer Price Index For All Urban Consumers: All Items, seasonally adjusted, quarterly observations constructed from monthly data, index 2000 = 100. Source: FRED, http://research.stlouisfed.org/fred2/.

Nominal Wage

Hourly Earnings (MEI), quarterly observations, index 2000 = 100. Source: OECD, www.oecd.org.

Oil Consumption

OECD Countries and World Petroleum (Oil) Demand (consumption), yearly observations, thousand barrels per day. Source:http://www.eia.doe.gov/.

The real GDP has been computed dividing the GDP by the GDP deflator. The real wage has been computed dividing the hourly earnings by the CPI. The real oil price has been computed dividing the nominal oil price by the CPI.

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