IMPACT ON WELFARE OF COUNTRY HETEROGENEITY IN A CURRENCY UNION

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Impact on welfare of country heterogeneity in a currency union*

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Abstract

We build a two-country DSGE model for a currency union, with habit formation, product and labour differentiation and nominal rigidities, and monetary policy follows an ad-hoc rule. The main innovation is the incorporation of several sources of heterogeneity and the assessment of its impact on welfare.

From the formal utility-based welfare analysis, we find that nominal rigidities are the most important source of heterogeneity. In a currency union where the central bank responds area wide and does not take into account national differences, it would be desirable to lower the overall level of rigidity in both countries at the same time, as there are significant welfare losses when country heterogeneity rises. A comparison of different policy rules allows us to conclude that rules that weigh more inflation relatively to the output gap provide the best result in terms of welfare. We also find out that if the central bank can take into account differences in nominal rigidities levels between countries, then it is preferable to react more strongly to the more rigid country.

Keywords: DSGE models, currency union, monetary policy rules, heterogeneous countries, nominal rigidities, welfare

JEL code: E52, E58

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1 Introduction

Since 1999, fifteen European countries have abandoned their national currencies and autonomous monetary policy in favour of the European Monetary Union (EMU). This can be considered as a "live experience" of the Optimal Currency Areas (OCA) theory and has motivated numerous studies on this area of research. According to this theory, it is more advantageous for various regions to share the same currency together when there is a sufficient level of synchronization and integration of trade and labour markets among the regions, i.e., when regions are similar enough. Despite the increased economic integration between European countries, namely regarding trade and financial markets, there are member countries which have shown persistent differentials against the euro area, namely regarding inflation and output growth. These differentials can be explained by an ongoing convergence process, but there may also exist structural differences among countries, such as different features in goods, labour or capital markets that justify diverging economic dynamics among countries.

In this paper, we are interested in understanding the implications of having heterogeneous countries and a common monetary policy in a currency area, both for the area wide and for each member country. The model is quite general and can be applied to any currency area. Two main sources of heterogeneity are considered: (i) differences in consumer preferences regarding the country where the goods are produced (home bias), since consumers in the European Union may prefer to consume national goods, and (ii) differences in wage and price setting mechanisms, as there are studies that point out the existence of different levels of nominal and real rigidity (Dhyne et al., 2005; Dickens et al., 2006, among other papers from the Inflation Persistence Network of the ECB). This analysis is developed under the framework of a two-country Dynamic Stochastic General Equilibrium (DSGE) model, including habit formation, product and labour differentiation, monopolistic competition and nominal rigidities. This type of models is currently frequently used for monetary policy analysis, given that they seem to be able to replicate well the behaviour of main macroeconomic variables in response to a wide set of shocks (Smets and Wouters, 2003).

Recently, literature has been studying the effects of heterogeneity among the regions of a currency union using DSGE models for more than one country. Benigno (2004) builds a two-region model with product differentiation between regions, monopolistic competition, price rigidity, labour immobility between regions and asymmetric shocks. When the monetary policy authority responds to the average of the area, weighted by the regions size, the optimal is not attained. But the optimal plan can be approximated by an inflation targeting policy which gives a higher weight to the inflation in the region where nominal rigidities are more striking. Gomes (2004) studies the implications for a currency area of different price rigidity degrees in response to common and specific shocks by using a calibrated model. Shocks, either common or specific, lead to significant differentials between countries, which are larger when shocks are idiosyncratic. From the comparison of different monetary policy rules, she concludes that rules that result in the best outcome for aggregate variables do not mean that they also lead to the best individual result. Interest rate smoothing stabilizes inflation and output, reduces countries differentials, but it also reduces inflation correlation between countries. A rule which responds to the output gap diminishes output volatility with prejudice for inflation volatility
and decreases output volatility in the more rigid country while increasing it in
the other, reducing, therefore, output correlation between the countries.

There is another line of investigation more focused on estimation of these
type of models for the euro area, for example Jondeau and Sahuc (2008) and
Pytlarczyk (2005). The first of these papers estimates and compares a area-
wide model for the euro area with a multi-country model (Germany, France
and Italy) in terms the impact on welfare from ignoring the member countries’
heterogeneity. They find out that in the case of an optimal monetary policy
based on the area wide model, then there are relatively larger welfare losses
than when the optimal rule is derived from the multi-country model. Then, the
central bank should take into consideration the specific features of the countries
forming the currency area, both in terms of behavioral parameters and specific
shocks, as the welfare losses are due to the use of a sub-optimal forecasting
model, instead of the use of a policy rule which responds to the aggregate
variables. Pytlarczyk’s (2005) estimated model for Germany and the remaining
euro area seems to allow a consistent analysis of the interaction between these
two regions. This model is slightly more evolved than Jondeau and Sahuc (2006),
as it includes some features present in Smets and Wouters (2003) such as capital
and an adjustment cost of capital, price and wage rigidity à la Calvo, product
and labour differentiation and external habit formation.

The model presented in our paper follows the line of research of the above
mentioned papers. Our main innovation in comparison to the current literature
is the incorporation of more sources of heterogeneity, particularly an interaction
between wage and price rigidity, and the assessment of its impact on wel-
fare, through the use of a quadratic approximate welfare measure (Benigno and
Woodford, 2004).

The model is calibrated and the impact of common shocks$^1$ to a homogeneous
union is simulated. We find that the model is able to replicate quite well the
usual responses to shocks found in the literature. Regarding the welfare analysis,
we obtain interesting results. First, heterogeneity on the nominal rigidities has
important consequences on welfare. In a currency union where the central bank
responds to the aggregate and does not take into account national differences,
it is preferable to increase flexibility in both countries and in both wages and
prices, as there are significant overall welfare losses for both economies when
countries attempt to make only wages or prices more flexible, or when only a
single country is flexible. Second, the comparison of different policy rules allows
us to conclude that rules that weigh more inflation and give a low weight to the
output gap provide the best result in terms of welfare. If the central bank can
observe national differences, then it would be better, in terms of the area wide
welfare, to give more importance to the more rigid country.

We abstract from fiscal policy issues, making the simplifying assumption
that there is no government. This assumption is made since we are more inter-
ested in assessing the impacts of different sources of country heterogeneity in a
currency union instead of the interactions between monetary and fiscal policy.
Nonetheless, we acknowledge that when fiscal policy is taken into account, the
negative impacts of asymmetries between countries or asymmetric shocks in a
currency union become less relevant. Adão et al. (2006) argue that in a cur-

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$^1$ There are four shocks considered: preferences, labour supply, technology and monetary
policy.
currency union with price rigidities, asymmetric countries or shocks and incomplete international financial markets, fiscal policy can offset the negative impacts of these aspects and eliminate the costs of a currency union, as long as labour is not mobile across countries.

The paper is structured as follows. Section 2 presents and describes the model, which will be calibrated and simulated in section 4. In section 3, we derive the welfare function according to a linear-quadratic approximation of the utility function. Afterwards, we discuss the impacts of heterogeneity, namely through a welfare analysis for each country and for the aggregate, and taking into account the various policy rules considered (subsection 3). Section 5 concludes and presents directions for future research.

2 Description of the model

We build a currency union model consisting of two economies, the domestic economy (variables denoted by D and parameters without an asterisk) and the foreign economy (variables denoted by F and parameters with an asterisk). The two countries form together a currency area, meaning that they share the same currency and have a common central bank that implements monetary policy for the aggregate. The population of the aggregate area is a continuum of identical and infinitely lived agents in the interval $[0, 1]$ (aggregate size is then normalized to 1), who produce a bundle of differentiated goods. Households are denoted by $j$. For the residents in the domestic economy, we have $j \in [0, n]$, and $j \in (n, 1]$ for residents in the foreign economy. Therefore, $n$ is the relative size of the home economy. Similarly, each firm produces one differentiated good $i$. Then, index $i$ denotes both firms and goods. Relative output size of each economy corresponds to the relative population size. When $i \in [0, n]$, the firm belongs to the home economy and when $i \in (n, 1]$, it belongs to the foreign economy. In order to easily identify where the household or firm belong to, whenever considered adequate, we will denote the household or firm belonging to the foreign country with an asterisk ($j^*$ or $i^*$).

All goods are tradable, there is free trade of goods and financial markets are complete. However, labour markets are specific to each country, i.e., there is no mobility of labour between the two countries. Figure 1 presents a schematic representation of the model.

The model follows closely DSGE models used recently in the literature. Indeed, we follow closely the structure of Smets and Wouters (2003) for the euro area. However, we simplify by excluding capital from our model. Adjustment between countries occurs through the goods market, since labour is restricted to each country. The Smets and Wouters (2003) model structure is applied to a two-country model, which brings it close to Benigno (2004) and Jondeau and Sahuc (2008). These models assume optimal wage setting, while in the model we develop here we introduce rigidity in wage setting. Evidence from the euro area suggests that wages are rigid, specially downwards, and that wage rigidity differs between countries (Dickens et al., 2006).

Both prices and wages are set according to a Calvo mechanism with indexation to past inflation. Calvo price/wage setting mechanism is the most commonly mean of introducing price/wage rigidity in the recent literature. It is an useful feature as it can be solved without explicitly tracking the distribution
of prices across firms and it is able to capture the factors that contribute to nominal stickiness (Christiano et al., 2005). Other models of staggered price setting introduce costs of price adjustment (Rotemberg, 1982, 1996). Although the Rotemberg sticky price model and the Calvo price model lead to a similar Phillips curve, they have different implications for micro data: the Rotemberg model implies a single price in the micro data, while the Calvo model has implicit a distribution of prices among firms, which seems to be more plausible. There are also models with staggered price setting using Taylor contracts, which imply a certain time between price adjustments (Chari et al., 2000), but can be criticized by not accounting for the sluggish response of inflation adjustment. Regarding wage stickiness, Taylor wage contracts are also used in the literature, which will impact on price rigidity. Indeed, with these wage contracts, prices display inertia but the inflation rate does not need to show inertia (Walsh, 2003).

### 2.1 Households and consumption

Households in each economy consume differentiated goods, either produced internally or imported. All households within each economy share the same preferences and endowments but supply to firms resident in the respective country differentiated labour. There is heterogeneity in households behaviour across countries. The representative household \( j \) in both economies seeks to maximize
its expected discounted utility, where the discount factor $\beta$ is common to the area wide:

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t (j)$$ (1)

The instantaneous utility function $U_t (j)$ shares the same functional form for both economies, depending positively on consumption ($C_D^t, C_F^t$) and negatively on labour ($L_D^t, L_F^t$); but it can differ in respect to the consumption habit ($H_D^t, H_F^t$), the relative risk aversion coefficients on consumption ($\sigma_c, \sigma_c^*$) and on labour supply ($\sigma_l, \sigma_l^*$) and the preference ($\varepsilon_D^t, \varepsilon_D^t$) and labour supply ($\varepsilon_L^D, \varepsilon_L^F$) shocks.

The instantaneous utility function of the representative household $j$ in the domestic economy and $j^*$ in the foreign one are, respectively:

$$U_t^D (j) = \varepsilon_D^t \left[ \frac{1}{1 - \sigma_c} (C_D^t (j) - H_D^t)^{1 - \sigma_c} - \frac{\varepsilon_L^D}{1 + \sigma_l} L_D^t (j)^{1 + \sigma_l} \right]$$ (2)

$$U_t^F (j^*) = \varepsilon_F^t \left[ \frac{1}{1 - \sigma_c^*} (C_F^t (j^*) - H_F^t)^{1 - \sigma_c^*} - \frac{\varepsilon_L^F}{1 + \sigma_l^*} L_F^t (j^*)^{1 + \sigma_l^*} \right]$$

Households present external habit formation, in the sense that their utility depends not only on current consumption but also on how it differs from a proportion of the previous period total consumption in the respective economy: $H_D^t = h C_D^{t-1}$ and $H_F^t = h^* C_F^{t-1}$, where $h$ ($h^*$) is the habit persistence parameter (in line with the "catching up with the Joneses" argument presented in Abel, 1990). Following the recent literature (Smets and Wouters, 2003; among others), including external habit persistence seems to provide a greater correspondence to consumption behaviour, which seems to be more persistent and to respond more gradually to economic shocks, as consumers dislike large and rapid changes in consumption or can not change their consumption rapidly (Fuhrer, 2000).

 Consumers in both countries consume goods produced in either country. Thus, total consumption in the home economy includes the consumption of internally produced goods ($C_{D,t}$) and imported goods ($C_{F,t}$) from the foreign country. The consumption baskets of the representative households in the home and foreign economies are given by (following Jondeau and Sahuc, 2008):

$$C_D^t (j) = \frac{(C_{D,t} (j))^\varpi (C_{F,t} (j))^{1-\varpi}}{\varpi (1-\varpi)^{(1-\varpi)}}$$ (3)

$$C_F^t (j^*) = \frac{(C_{D,t} (j^*))^{\varpi^*} (C_{F,t} (j^*))^{1-\varpi^*}}{\varpi^* (1-\varpi^*)^{(1-\varpi^*)}}$$ (4)

In our model we include the hypothesis of the existence of home bias in preferences, given by the parameter $\omega$ ($\omega^*$). In this way, $\omega$ ($\omega^*$) is the share of domestically produced goods in the total consumption in the home economy (remaining euro area). In case $\omega = 0.5$ ($\omega^* = 0.5$), then consumers do not distinguish goods by the country were they were produced. In case $\omega > 0.5$ ($\omega^* > 0.5$), consumers prefer goods produced in the home economy ($C_{D,t}$), i.e.,
we have a home bias in consumption preferences. In case $\omega < 0.5$ ($\omega^* < 0.5$), consumers prefer goods produced in the foreign economy ($C_{F,t}$).

$C_{D,t}(j)$ ($C_{F,t}(j)$) is the consumption by household $j$ of domestically (foreign) produced goods, which are imperfect substitutes and can either be consumed in the country where they are produced in or can be exported and consumed by households in the other country. In this way, $C_{D,t}(j)$ ($C_{F,t}(j)$) is an index given by the following CES aggregator:

$$
C_{D,t}(j) = \left[ \left( \frac{1}{n} \right)^\varpi \int_0^n C_{D,t}(i,j)^{\varpi-1} di \right]^{\frac{\varpi}{\varpi-1}}
$$

$$
C_{F,t}(j) = \left[ \left( \frac{1}{n} \right)^\varpi \int_0^1 C_{F,t}(i^*,j)^{\varpi-1} di^* \right]^{\frac{\varpi}{\varpi-1}}
$$

$C_{D,t}(i,j)$ ($C_{F,t}(i^*,j)$) is the consumption by household $j$ of the generic good $i$ ($i^*$) produced in the home (foreign) economy. Since goods produced in the same country are differentiated, $\theta$ ($\theta^*$) denotes the elasticity of substitution between goods produced in home (foreign) economy. These goods are then aggregated taking into account the product differentiation and the production size of the country where they are produced.\(^2\)

Households maximize their intertemporal utility function subject to an intertemporal budget constraint which states that their income from labour, dividends and financial markets applications will be fully used every period for consumption and transactions in financial markets. The total income of each household is given by the labour income ($w_{D,t}$ ($w_{F,t}$) denotes the real wage) and dividends from participating in the imperfectly competitive firms ($Div^D_t$ for households in D and $Div^F_t$ for households in F), which are denominated in units of the consumption basket of the respective country. Households also receive income from the applications made in the bond market in the previous period. Indeed, households can trade area wide riskless bonds $B_t$. These are one-period bonds with price $b_t$. Each domestic (foreign) household detains the same amount of $B_t(j)$ ($B_t(j^*)$). The bond market must be balanced in order to avoid the existence of Ponzi games. Therefore, the financial market is at equilibrium at each moment when the area aggregate is neither at a debtor nor at a creditor position ($nB_t(j) + (1-n)B_t(j^*) = 0$). The transversality condition holds and neither of the economies individually can assume a permanent debtor or creditor position ($\lim_{t \to \infty} b_t nB_t(j) = 0$ and $\lim_{t \to \infty} b_t (1-n)B_t(j^*) = 0$).

The income from applications in bonds made in the previous period and the transactions made in the current period are defined in nominal terms. In order to make it consistent with the remaining budget constraint, we have to divided it by $P_t^{D*}$ ($P_t^{F*}$), the consumer price index for the home (foreign) economy.

\(^2\)In this way, the following aggregation expressions apply:

$C_{D,t}^D = \int_0^n C_{D,t}(j) dj$ for the total consumption of home produced goods in the home economy;

$C_{D,t}^{D*} = \int_0^1 C_{D,t}(j^*) dj^*$ for the total consumption of home produced goods in the foreign economy;

$C_{F,t}^D = \int_0^n C_{F,t}(j) dj$ for the total consumption of foreign produced goods in the home economy;

$C_{F,t}^{D*} = \int_0^1 C_{F,t}(j^*) dj^*$ for the total consumption of foreign produced goods in the foreign economy.
Households also have access to a country-specific state-contingent security \( S^D_t (S^F_t) \), denominated in units of the domestic (foreign) consumption basket. This security allows an harmonization between households in the same country, so that all the households are similar regarding consumption and area wide common asset holdings. Within each region, there is a zero net supply of these state-contingent securities, i.e., \( \int_0^S S^D_t (j) dj = 0 \) and \( \int_0^S S^F_t (j^*) dj^* = 0 \). In this way, we define the intertemporal budget constraint as follows (for domestic households and for foreign households, respectively):

\[
\frac{b_t}{P^D_t} \frac{b_{t-1}(j)}{P^D_{t-1}} = \frac{b_{t-1}(j) + w_{D,t} (j) L^D_t (j) + Div^D_t (j) + S^D_t (j) - C^D_t (j)}{P^D_t} \quad (6)
\]

\[
\frac{b_t}{P^F_t} \frac{b_{t-1}(j^*)}{P^F_{t-1}} = \frac{b_{t-1}(j^*) + w_{F,t} (j^*) L^F_t (j^*) + Div^F_t (j^*) + S^F_t (j^*) - C^F_t (j^*)}{P^F_t} \quad (7)
\]

The optimization problem of the representative household in each economy resumes to the maximization of equation (1) with respect to consumption and both asset type holdings, subject to the constraint (6), i.e., corresponds to the optimization of the following Lagrangian:

\[
L = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{1-\sigma_c} \left[ \left( \frac{C^D_t (j) - H^D_t (j)}{P^D_t} \right)^{1-\sigma_c} - \frac{\varepsilon_t^{LD}}{1 + \sigma_t} \left( \frac{C^D_t (j) - H^D_t (j)}{P^D_t} \right)^{1+\sigma_t} \right] - \lambda_{D,t} \frac{b_t B_t (j) - B_{t-1} (j)}{P^D_t} \right\}
\]

The first-order conditions yield the usual Euler equation, i.e., the optimal consumption flows over time, when we derive the Lagrangian with respect to \( B_t \) (equation 7), and the marginal utility from consumption when we derive the Lagrangian with respect to \( C^D_t \) (equation 8), where \( R_t = \frac{1}{b_t} \) is the gross nominal rate of return on bonds.

\[
E_t \left[ \frac{\lambda_{D,t+1} R_t P^D_t}{\lambda_{D,t} P^D_t} \right] = 1 \quad (7)
\]

\[
\lambda_{D,t} = \varepsilon_t^{bD} (C^D_t - H^D_t)^{-\sigma_c} \quad (8)
\]

Similar equations are found for the foreign economy.

### 2.2 Labour supply and wages

Households are competitive monopolist suppliers of differentiated labour to the firms (Erceg et al., 2000). In this way, households sell their labour services to

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3These securities work as a transfer/payment between households in the end of the period, when the state of the nature is observed. The average value of \( S_t \) is null, since all transfers net out. Therefore, the household will choose its consumption and bond holdings assuming the expected value of the state-contingent securities as zero. In this way, the choice of consumption and bond-holdings will equal between all households. When the state of the nature is observed, then households will know their respective income and will pay/receive the \( S_t \) amount between them that allows them to match the consumption and bond-holdings decided in the beginning of the period.
firms and set their wages in each period in order to maximize their utility given their budget constraint.

Labour markets are specific to each economy and there is no mobility of labour between the home and the foreign economy. There is rigidity on wages and in both economies wages are set following a Calvo mechanism. This means that not all households can adjust their wages optimally on every period. A particular household can reoptimize its nominal wage only when it receives a signal to do so. When optimizing the new wage, the household takes into account the likelihood of being able to reoptimize its wage again in the future (Erceg et al., 2000; Smets and Wouters, 2003). When the household does not receive this signal to reoptimize, it adjusts wages as a function of past inflation.

The probability of a household in the home economy receiving the signal to optimize its nominal wage to $\tilde{W}_{D,t}(j)$ is given by $1 - \xi_w^D$. The rest of the households are not able to reoptimize their wages (with probability $\xi_w^D$) and therefore can only adjust their wages according to past inflation. Then, the wage is set as follows:

$$W_{D,t}(j) = \begin{cases} \tilde{W}_{D,t}(j) & \text{with probability } 1 - \xi_w^D \\ \frac{p_{D,t-1}}{p_{D,t-2}} \gamma_w W_{D,t-1}(j) & \text{with probability } \xi_w^D \end{cases} \quad (9)$$

The parameter $\gamma_w$ in equation (9) is the degree of wage indexation. When $\gamma_w = 0$ there is no indexation and the wages that cannot be reoptimized remain constant; if $\gamma_w = 1$, it implies perfect indexation to past consumer inflation.

Given labour differentiation, domestic firms transform the differentiated labour services provided by domestic households into a labour index $L_t^D$ that follows a Dixit-Stiglitz type aggregator (Erceg et al., 2000):

$$L_t^D = \left[ \left( \frac{1}{n} \right)^{\frac{1}{\varphi}} \int_0^n (L_t^D(j))^{\frac{\varphi-1}{\varphi}} \, dj \right]^{\frac{\varphi}{\varphi-1}} \quad (10)$$

$L_t^D(j)$ is the labour supplied by household $j$. The parameter $\varphi$ represents the elasticity of substitution between different types of labour services within the home economy. The nominal wage index at home ($W_{D,t}$) is also defined in a similar way:

$$W_{D,t} = \left[ \frac{1}{n} \int_0^n (W_{D,t}(j))^{1-\varphi} \, dj \right]^{\frac{1}{1-\varphi}} \quad (11)$$

$W_{D,t}(j)$ denotes the nominal wage negotiated by household $j$ at date $t$. In this way, household $j$ faces the following labour specific demand from all firms in the home economy:

$$L_t^D(j) = \left( \frac{W_{D,t}(j)}{W_{D,t}} \right)^{-\varphi} \frac{L_t^D}{n} \quad (12)$$

Households set their wages in order to optimize their intertemporal objective function (1) subject to the budget constraint (6) and the above labor demand
The optimization problem leads to the following mark-up equation for the optimized nominal wage $\bar{W}_{D,t}$:

$$\bar{W}_{D,t} \frac{E_t}{p_{D,t}} \sum_{k=0}^{\infty} \left( \beta \xi_w \right)^k \frac{\varphi - 1}{\varphi} \bar{L}_{t+k}^D U'_{C_{t+k}} \left( \frac{p_{C,t+k}^D}{p_{C,t-1}^D} \right) ^{\gamma_w} = -E_t \sum_{k=0}^{\infty} \left( \beta \xi_w \right)^k \bar{L}_{t+k}^D U'_{L_{t+k}}$$

Equation (13) states that the optimal wage will be set at the level where the disutility from an additional working hour equals a mark-up over the increase in marginal utility from consumption due to the higher working hours. The terms $U'_{C_{t+k}}$ and $U'_{L_{t+k}}$ denote, respectively, the marginal utility from consumption and the marginal disutility from labour. $L_{t+k}^D$ is the labour supplied at moment $t + k$ by household $j$ which reoptimized its wage at moment $t$, i.e., is the labour supply in time given that the household was allowed to reoptimize its wage in the initial moment.

The law of motion of the home aggregate index of the nominal wage can be derived from equations (9) and (11) is given by:

$$(W_{D,t})^{1-\varphi} = \xi^D \left[ \frac{W_{D,t-1}}{W_{D,t-2}} \left( \frac{p_{D,t-1}}{p_{D,t-2}} \right)^{\gamma_w} \right]^{1-\varphi} + \left( 1 - \xi^D \right) \left( \bar{W}_{D,t} \right)^{1-\varphi}$$

We get similar expressions for the foreign economy. The wage indexation for the households which can not reoptimize is $W_{F,t} (j^*) = \left( \frac{p_{F,t-1}}{p_{F,t-2}} \right)^{\gamma_w} W_{F,t-1} (j^*)$.

The labour demand in this country is given by $L_{F,t} (j^*) = \left( \frac{W_{F,t} (j^*)}{W_{F,t}} \right)^{1-\varphi} L_{F,t} ^1$, while aggregate labour and aggregate wage are defined by the equations:

$$L_{F,t} = \left[ \left( \frac{1}{1-n} \right)^{1-\varphi} \int_0^1 \left( L_{F,t} (j^*) \right)^{1-\varphi} dy \right] ^{\varphi-1}$$

$$W_{F,t} = \left[ \frac{1}{1-n} \int_0^1 \left( W_{F,t} (j^*) \right)^{1-\varphi} dy \right] ^{1-\varphi}$$

Taking the optimization problem similar to the home economy, i.e., the maximization of the intertemporal utility function regarding wage subject to the

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4 The average optimal wage equation will be similar to the individual optimal wage. Although households provide differentiated labour and, therefore, face different wages, they still share the same utility function and the same budget constraint and are not subject to individual shocks. Thus, we can consider them as representative households in the sense that the decision they take is the same and they will all choose the same wage (Erceg et. al, 2000; Woodford, 2003).

5 Recall that $U'_{C_{t+k}} = \xi^D \left( C_{t+k}^D (j) - H_{t+k}^D \right)^{-\sigma_e}$ and $U'_{L_{t+k}} = \xi^D \xi^L \left( L_{t+k}^D \right)^{1-\sigma_e}$. 

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budget constraint and the labour demand equation, we reach a similar mark-up equation for the optimized wage in the foreign country:

$$\frac{W_{F,t}}{P_{F,t}} E_t \sum_{k=0}^{\infty} \left( \beta \xi_w^F \right)^k \frac{\varphi^*}{\varphi^* - 1} \tilde{L}_{t+k}^F U'^F_{t+k} \left( \frac{P_{t+k}^F}{P_{t-k}^F} \right)^{\gamma_w^*} = -E_t \sum_{j=0}^{\infty} \left( \beta \xi_w^F \right)^k \tilde{L}_{t+k}^F U'^F_{t+k}$$

The law of motion of the foreign aggregate index of the nominal wage follows

$$(W_{F,t})^{1-\varphi^*} = \xi_w^F \left[ W_{F,t-1} \left( \frac{P_{t-1}^F}{P_{t-2}^F} \right)^{\gamma_w^*} \right] + (1 - \xi_w^F) \left( W_{F,t} \right)^{1-\varphi^*}$$

### 2.3 Firms

There is a continuum of imperfectly competitive firms. Firms producing in the home economy belong to the interval $[0, n]$, while firms producing in the foreign country belong to the interval $(n, 1]$. Similarly to what was defined for households, firms may show different behaviour according to the economy they belong to, i.e., the parameters may differ between countries. Firms produce differentiated goods which are bundled into homogeneous domestic and foreign baskets of goods which can be freely traded among the area wide. The homogeneous domestic and foreign goods ($Y_{t,D}^D$ and $Y_{t,F}^F$) are given by the following Dixit-Stiglitz type aggregator, which takes into account households preferences (Erceg et al., 2000):

$$Y_{t,D}^D = \left[ \frac{1}{n} \right]^{\frac{1}{n}} \int_0^n Y_{t,D}^D (i) \frac{1}{i} di$$

and

$$Y_{t,F}^F = \left[ \frac{1}{1-n} \right]^{\frac{1}{1-n}} \int_1^n Y_{t,F}^F (i) \frac{1}{i} di$$

The domestic firm $i$ only produces one good $i$, which is differentiated from the goods produced by other domestic firms. Firms only have one productive factor, labour. In this way, and for the home economy, the individual production function ($Y_{t,D}^D (i)$) depends on labour ($L_{t,D}^D (i)$), productivity ($A_{t,D}^D$) and fixed costs ($\Phi_{t,D}^D$).\footnote{Following Christiano et al. (2005), fixed costs are included so that there is a minimum level of production that covers the fixed costs. Fixed costs will guarantee that steady-state profits are null.}

$$Y_{t,D}^D (i) = A_{t,D}^D L_{t,D}^D (i) - \frac{\Phi_{t,D}^D}{n}$$

Productivity differs from economy to economy, but in both it is assumed to follow an AR(1) process: $A_{t,D}^D = (1 - \rho_a) \hat{A}_t^D + \rho_a A_{t-1}^D + \eta_{a,t}$, where $\hat{A}_t^D$ is the long-term productivity, $\rho_a$ is the persistence parameter and $\eta_{a,t}$ is a random shock.

Cost minimization conditions imply that the demand from all households for goods produced by firm $i$ follows:
\[ Y_t^D(i) = \left( \frac{P_{D,t}(i)}{P_{D,t}} \right)^{-\theta} Y_t^D \]  

(19)

where \( P_{D,t}(i) \) is the price of good \( i \) and \( P_{D,t} \) is the aggregate price index of home produced goods. All firms share the same marginal costs, given by the nominal wage weighted by productivity:

\[ MC_t^D = \frac{W_{D,t}}{A_t^D} \]  

(20)

Similarly to what was defined for wages, prices are also set by firms according to a Calvo mechanism. At each period \( t \), firm \( i \) is allowed to reoptimize and chooses the price \( \hat{P}_{D,t}(i) \) with probability \( 1 - \xi_p^D \). If the firm does not receive the signal to reoptimize (with probability \( \xi_p^D \)), then it sets its price according to past inflation. In this way, price is set according to

\[
P_{D,t}(i) = \begin{cases} 
\hat{P}_{D,t}(i) \text{ with probability } 1 - \xi_p^D \\
\left( \frac{P_{D,t-1}}{P_{D,t-2}} \right)^{\gamma_p} P_{D,t-1}(i) \text{ with probability } \xi_p^D 
\end{cases} \]  

(21)

The low branch of equation (21) gives the expression for the price adjustment indexed to previous period producer inflation for domestic firms which can not reoptimize their wages at period \( t \). The parameter \( \gamma_p \) is the degree of price indexation to past inflation. If \( \gamma_p = 0 \), then no adjustment is made and prices remain fixed; on the other hand, when \( \gamma_p = 1 \), prices adjust perfectly to the previous period observed inflation.

The price index of goods produced by all domestic firms is given by the following Dixit-Stiglitz type aggregator:

\[ P_{D,t} = \left[ \frac{1}{n} \int_0^n P_{D,t}(i)^{1-\theta} \, di \right]^{\frac{1}{1-\theta}} \]  

(22)

The firm’s objective is to set the price which maximizes its profits, taking into account the probability it has to reoptimize its price in the future. This will lead to a mark-up equation for the optimal price \( \hat{P}_{D,t}(i) \) for each firm. Since this is a representative agent model, then every agent will follow the same "rule" for the price formation as there are no individual specific shocks (Woodford, 2003; Jondeau and Sahuc, 2008; Pytlarczyk, 2005), and the individual price mark-up is defined in aggregated terms for the home economy as follows:

\[
E_t \sum_{k=0}^{\infty} \left( \beta \xi_p^D \right)^k \rho_{t+k} Y_{t+k}^D \left[ \frac{\hat{P}_{D,t}}{P_{D,t}} \frac{P_{D,t}}{P_{D,t+k}} \left( \frac{P_{D,t+k-1}}{P_{D,t-1}} \right)^{\gamma_p} \right] - \frac{\theta}{\theta - 1} m_{D,t+k} = 0 \]  

(23)

where \( \rho_{t+k} = \frac{U_{C_{D,t+k}}}{U_{C_{D,t+k}}} \) and \( \beta \rho_t \) is the discount factor used by the shareholders-households and \( m_{D,t} \) are the real marginal costs. Equation (23) states that the optimal price will be set at a level consistent with the mark-up over current and expected future marginal costs.
Taking into account that prices are set according to a Calvo mechanism, then we can define the law of motion of the home producer price index, derived from equations (21) and (22):

\[
(P_{D,t})^{(1-\theta)} = \xi_p^D \left[ P_{D,t-1} \left( \frac{P_{D,t-1}}{\bar{P}_{D,t-2}} \right)^\gamma_p \right]^{(1-\theta)} + \left( 1 - \xi_p^D \right) \left( \bar{P}_{D,t} \right)^{(1-\theta)}
\]

(24)

The way foreign firms set their prices is quite similar to home firms, with the caveat of the different parameters. Therefore, the foreign mark-up equation for the optimal price \( \bar{P}_{F,t} \) is given by:

\[
E_t \sum_{k=0}^{\infty} \left( \beta \xi_p^F \right)^k \rho_{t+k}^* Y_{t+k}^F \left[ \bar{P}_{F,t} \left( \frac{P_{F,t}}{P_{F,t+k}} \right)^{\gamma_p} - \theta^* \frac{\theta^*}{\theta^* - 1} \left( \bar{m}^c_t \right) \right] = 0
\]

(25)

and the foreign producer price index follows a similar law of motion:

\[
(P_{F,t})^{(1-\theta^*)} = \xi_p^F \left[ P_{F,t-1} \left( \frac{P_{F,t-1}}{P_{F,t+k}} \right)^{\gamma_p} \right]^{(1-\theta^*)} + \left( 1 - \xi_p^F \right) \left( \bar{P}_{F,t} \right)^{(1-\theta^*)}
\]

(26)

The law of one price holds for each good individually taken, meaning that it will have the same price independently where it is consumed. Then, producer prices are the prices at which goods are sold, either at home or in the foreign country. For example, firm \( i \) sets the price of good \( i \), which is produced domestically, and sells this good at price \( P_{D,t}(i) \), which is the same price for domestic consumers and for foreign consumers. Consumer price indexes are determined according to the share of home produced goods and imported goods in the consumption basket (\( \varpi \)):

\[
P_{cD}^t = (P_{D,t})^{(1-\varpi)} \quad \text{and} \quad P_{cF}^t = (P_{F,t})^{(1-\varpi^*)}
\]

(27)

Given equations (27) for each economy consumer price indexes and the law of one price, then we can establish a relation between consumer and producer prices in both economies. Consumer price index can differ between countries due to the existence of a home bias in consumption, i.e., PPP will not hold whenever \( \varpi \neq \varpi^* \). This differs from Benigno (2004), which assumes that PPP holds since he does not consider the existence of home bias and the share of each countries goods in the consumption basket equals the countries’ size.

\[
\frac{P_{cF}^t}{P_{cD}^t} = \left( \frac{P_{F,t}}{P_{D,t}} \right)^{\varpi-\varpi^*}
\]

(28)

The model does not consider the hypothesis of pricing-to-market (Obstfeld and Rogoff, 1996; Betts and Devereux, 2000), as price discrimination is not feasible given the characteristics of the currency union. The two countries belong to the same currency union with free trade in the goods market. We do not consider transaction costs or trade tariffs and there is no nominal exchange

\footnote{Note that if both economies share the same home bias, then it is not possible to define relative prices.}
rate as countries share the same currency. If firms would decide to set prices for the exported goods differently from the goods sold domestically, then there would be arbitrage opportunities and the prices of goods exported would tend to approach the price of the goods consumed internally. There can be indeed differences between the prices of the goods produced in different countries, since countries have different production technologies, or differences in the price index of the baskets of goods of the two countries, as consumers may have different preferences.

We can also define the terms of trade as the relation between the producer prices of both economies:

\[ T_t = \frac{P^{F}_{t}}{P^{D}_{t}} \]  

(29)

### 2.4 Market equilibrium

Consider the home economy. The goods market is in equilibrium when the production of home produced goods equals home and external demand.

\[ Y^{D}_{t}(i) = nC^{D}_{D,t}(i) + (1 - n)C^{F}_{D,t}(i) \]  

(30)

Equation (30) gives the market clearing condition for the home produced good \( i \). The good \( i \), produced by domestic firm \( i \), can be consumed internally \( (C^{D}_{D,t}(i)) \) or can be exported \( (C^{F}_{D,t}(i)) \), at the same price in either case. The share of internal consumption and exports on domestic output is given by the size of the economy for all types of goods. The consumption of the good \( i \) can be expressed in terms of total consumption of domestic goods, taking into account that there is product differentiation and that the elasticity of substitution between goods from the same country is \( \theta \).

\[ C^{D}_{D,t}(i) = \frac{1}{n} \left( \frac{P^{D}_{D,t}(i)}{P^{D}_{t}} \right)^{-\theta} C^{D}_{D,t} \]  

(31)

The total consumption of domestic goods can also be rewritten in terms of the total consumption index of the home economy, taking into account consumer prices and the existence of a home bias:

\[ C^{D}_{D,t} = \varpi \left( \frac{P^{D}_{F,t}}{P^{D}_{t}} \right) C^{D}_{i} \]  

(32)

With a similar rationale, exports of the good \( i \) can also be defined in terms of the foreign total consumption index:

\[ C^{F}_{D,t}(i) = \frac{1}{n} \left( \frac{P^{F}_{D,t}(i)}{P^{D}_{t}} \right)^{-\theta} C^{F}_{D,t} = \frac{1}{n} \left( \frac{P^{F}_{D,t}(i)}{P^{D}_{t}} \right)^{-\theta} \varpi \left( \frac{P^{F}_{F,t}}{P^{D}_{t}} \right) C^{F}_{i} \]  

(33)

Replacing the above expressions in equation (30), and taking into account that there is free trade of goods in the whole of the area, that there is only one currency and that the law of one price holds, we get the following market clearing condition for the good \( i \):
\[ Y_t^D (i) = \left( \frac{P_{D,t}}{P_{D,t} (i)} \right) ^\vartheta \left[ \frac{1}{\varpi} P_{t}^{D^D} C_{t}^{D} + \frac{(1 - n)}{n} \varpi^* P_{t}^{F} C_{t}^{F} \right] \]  

(34)

After some simple algebra, the aggregate domestic goods market clearing condition (per capita) results in the following equation, using the definition for the terms of trade:

\[ Y_t^D = T_t^{(1-\varpi)} \varpi C_t^D + \frac{(1 - n)}{n} \varpi^* T_t^{(1-\varpi^*)} C_t^F \]  

(35)

In a similar way, we get for the foreign economy the following market clearing condition for the good \(i^*\):

\[ Y_t^F (i^*) = nC_{F,t}^{D^D (i^*)} + (1 - n) C_{F,t}^{F^F} C_{t}^{F} \]

\[ = \left( \frac{P_{F,t}}{P_{F,t} (i^*)} \right) ^\vartheta \left[ (1 - \varpi) \frac{n}{1-n} P_{t}^{D^D} C_{t}^{D} + (1 - \varpi^*) P_{t}^{F} C_{t}^{F} \right] \]

And for the aggregate foreign production, we have:

\[ Y_t^F = T_t^{\varpi} (1 - \varpi) \frac{n}{1-n} C_t^D + (1 - \varpi^*) T_t^{\varpi^*} C_t^F \]  

(36)

2.5 Area wide economy

The home economy and the foreign economy are linked and together they make a single currency area to which the common central bank reacts to. Thus, we have to define the area wide main conditions.

\[ Y_t = (Y_t^D)^n (Y_t^F)^{(1-n)} \]  

(37)

\[ C_t = (C_t^D)^n (C_t^F)^{(1-n)} \]  

(38)

\[ L_t = (L_{D,t})^n (L_{F,t})^{(1-n)} \]  

(39)

\[ \pi_t = (\pi_t^D)^n (\pi_t^F)^{(1-n)} \]  

(40)

Equations (37) to (40) give the main area wide variables, i.e., output, consumption, labour and consumer price inflation, respectively, as a weighted average of both economies. Consumer price inflation is defined as the rate of change of consumer prices, i.e., \(\pi_t^{C^D} = \frac{P_{t}^{C^D}}{P_{t-1}^{C^D}}\) and \(\pi_t^{C^F} = \frac{P_{t}^{C^F}}{P_{t-1}^{C^F}}\).

2.6 The log-linearized model

Given that the model shows a significant degree of nonlinearities, a straightforward solution is not available. Therefore, we follow the literature and approximate the model by log-linearizing it around the steady-state. The resulting model will be used for the simulations in section 4. The variables with a hat (\(^\hat{\cdot}\))

\(^8\)Appendix A presents the equations in the steady-state. Given its non-linearity, we do not present the explicit solution for the steady-state variables, but it can be proved that, given the calibrated parameters used along the paper, there is a unique and stable steady-state.
refer to the log-linearized variables around the steady state. We will define only
country-specific shocks (except the monetary policy shock), since it is the most
flexible option; we can easily consider area wide shocks by making the shock in
one country equal to the other country’s shock.

From equations (7) and (8), we get the consumption equation for the home
economy\(^9\):

\[
\hat{C}_t^D = \frac{h}{1 + h} \hat{C}_{t-1}^D + \frac{1}{1 + h} E_t \hat{C}_{t+1}^D + \frac{1 - h}{\sigma_e (1 + h)} \left( \hat{x}_t^bD - E_t \hat{x}_t^{bD} \right) - \frac{1 - h}{\sigma_e (1 + h)} \left( R_t - E_t \hat{\pi}_t^D \right)
\] (41)

Given the existence of habit formation in consumption, current consumption
dePENDS also on past consumption. The external habit parameter also influences
the way consumption reacts to the interest rate and the consumer price inflation,
as we would expect a lower sensitivity of current consumption to changes in the
real interest rate when habit is larger. Consumption is subject to an AR(1)
preference shock with an i.i.d. term (\(\hat{x}_t^bD = \rho \hat{x}_{t-1}^bD + \xi_t^D\)).

The real wage equation is derived from equations (13) and (14):

\[
\hat{w}_{D,t} = \beta \frac{1}{1 + \beta} E_t \hat{w}_{D,t+1} + \frac{1}{1 + \beta} \hat{w}_{D,t-1} + \frac{\beta}{1 + \beta} E_t \hat{\pi}_t^D - \frac{1 + \beta \gamma_w}{1 + \beta} \hat{\pi}_t^D - \frac{\gamma_w}{1 + \beta} \hat{x}_t^D - \frac{1}{1 + \beta} \left( 1 - \beta \frac{\hat{\pi}_t^D}{\xi_t^D} \right) \left( 1 - \frac{\hat{\pi}_t^D}{\xi_t^D} \right)
\times \left[ \hat{w}_{D,t} - \sigma_L \hat{L}_t^D - \frac{\sigma_c}{1 - h} \left( \hat{C}_t^D - h \hat{C}_{t-1}^D \right) - \hat{\pi}_t^D \right]
\] (42)

The real wage is set-up according to past and expected future real wage, to
past, current and future consumer price inflation and according to the di
derence between the real wage and the one that would prevail under flexible wage setting.
In case wages can not adjust every period to past inflation (\(\gamma_w = 0\)), then past
inflation will not influence the current wage and the impact of current inflation
will be smaller. The greater the wage rigidity (\(\xi_t^D\)), the labour demand elasticity
(\(\varphi\)) and the risk aversion coefficient on labour supply (\(\sigma_L\)), the lower the reaction
of current wage on optimal wage. Labour is subject to a AR(1) labour supply
shock with an i.i.d. term (\(\hat{\pi}_{t}^{LD} = \rho_{t} \hat{\pi}_{t-1}^{LD} + \xi_{t}^{LD}\)).

From equations (23) and (24) we get the producer price inflation equation:

\[
\hat{\pi}_{D,t} = \beta \frac{\gamma_p}{1 + \beta \gamma_p} E_t \hat{\pi}_{D,t+1} + \frac{1}{1 + \beta \gamma_p} \hat{\pi}_{D,t-1} + \frac{\gamma_p}{1 + \beta \gamma_p} \hat{\pi}_{D,t-1} + \frac{1 - \beta \xi_p^D}{\xi_p^D} \left( 1 - \frac{\hat{\pi}_t^D}{\xi_t^D} \right) \left( \hat{w}_{D,t} - \hat{A}_t^D \right)
\] (43)

Producer price inflation depends on past and expected future inflation and
on the current marginal cost. When the price indexation parameter \(\gamma_p\) is higher,
current producer price inflation is more sensitive to past inflation and less sensi
tive to expected future inflation. The effect of marginal costs on producer
price inflation depends on the price rigidity: the higher the price rigidity (\(\xi_p^D\)).

\(^9\)We only present the equations for the home economy in the main text. The equations for
the foreign economy are similar to the home economy and are presented in Appendix B.
the lower inflation will tend to be. The marginal cost is subject to an AR(1) productivity shock with an i.i.d. term \((A^D_t = \rho_A \hat{A}^D_t + \hat{\eta}_{A,t})\).

Taking (27) and (43), we can define the equation for the consumer price inflation:

\[ \hat{\pi}^c_t = w \hat{\pi}_{D,t} + (1 - w) \hat{\pi}_{F,t} \]  

From (29) we define the terms of trade expression:

\[ \hat{T}_t = \hat{\pi}_{F,t} - \hat{\pi}_{D,t} + \hat{T}_{t-1} \]  

Using equation (18), we can define the home aggregate production function as:

\[ \hat{Y}_t^D = \phi^D \left( \hat{A}_t^D + \hat{L}_t^D \right) \]  

where \(\phi^D = \left(1 + \frac{\Phi^D}{\hat{Y}^D} \right)\) is 1 plus the steady state proportion of home fixed costs over home output.

The market equilibrium condition is derived from (35) and is given by:

\[ \hat{Y}_t^D = \omega T^{1-\omega} \frac{C_D}{\hat{Y}^D} \left[ (1 - \omega) \hat{T}_t + \hat{C}_t^D \right] + \omega^* \frac{1 - n}{n} T^{1-\omega^*} \frac{C_F}{\hat{Y}^D} \left[ (1 - \omega^*) \hat{T}_t + \hat{C}_t^F \right] \]  

(47)

where the variables without a time subscript are the steady-state values.

The area wide main variables equations are calculated from equations (37) to (40):

\[ \hat{\pi}_t = n \hat{\pi}^c_t + (1 - n) \hat{\pi}^cF_t \]  

(48)

\[ \hat{Y}_t = n \hat{Y}^D_t + (1 - n) \hat{Y}^F_t \]  

(49)

\[ \hat{C}_t = n \hat{C}^D_t + (1 - n) \hat{C}^F_t \]  

(50)

\[ \hat{L}_t = n \hat{L}^D_t + (1 - n) \hat{L}^F_t \]  

(51)

Given the absence of external economies to the currency area, the absence of capital and savings and given that we imposed balanced accounts in every period, we have as a consequence the following aggregate equilibrium condition:

\[ \hat{Y}_t = \hat{C}_t \]  

(52)

Monetary policy stance follows a similar structure to the one in Smets and Wouters (2003). The common central bank tries to stabilize the area wide inflation at the steady-state level, taking into account also the output gap. The central bank has a preference for smoothing the interest rate path and responds to changes in the short-term in inflation and output. The central bank’s objective is to keep the inflation rate and the output at the steady state level. It follows the rule:

\[ \hat{R}_t = \gamma_R \hat{R}_{t-1} + (1 - \gamma_R) \left[ \gamma_{\pi} \hat{\pi}_t + \gamma_{Y} \hat{Y}_t \right] + \gamma_{\Delta\pi} (\hat{\pi}_t - \hat{\pi}_{t-1}) + \gamma_{\DeltaY} (\hat{Y}_t - \hat{Y}_{t-1}) + \hat{m}_t \]  

(53)
The parameters $\gamma_\pi$ and $\gamma_y$ give the weights of, respectively, inflation and output deviation from the steady state on the central bank policy rule; $\gamma_{\Delta \pi}$ and $\gamma_{\Delta y}$ weigh the changes of inflation and output, respectively. The parameter $\gamma_R$ is the interest rate persistence or the preference of the central bank for smoothing the interest rate path.

The central bank’s rule also includes a money AR(1) shock with an i.i.d. term ($\tilde{m}_t = \rho_m m_{t-1} + \xi_t^m$).

3 The welfare criterion

In this section, we compute the welfare function that will be used to assess the impact of country heterogeneity and the use of different policy rules by the common central bank. We follow mostly Benigno and Woodford (2004) for the case of sticky prices and wages and derive a linear quadratic approximation to the utility function of the representative household of each country.

To obtain the welfare function, first rewrite equation (2) so that we can separate the utility function into consumption and labour:

$$U^D = U^D(C_t^D, H_t^D, \varepsilon^D) = \frac{1}{1 - \sigma_c} \left( C_t^D - H_t^D \right)^{1 - \sigma_c} - \frac{\varepsilon^D}{1 + \sigma_i} L_t \left( \frac{1}{1 + \sigma_i} \right)^{1 + \sigma_i}$$

$$V^D = V^D(L_t^D(j), \varepsilon^D, \varepsilon^L)$$

$U(\cdot)$ denotes the utility from consumption and $V(\cdot)$ is the disutility from working. Then, the welfare function is given by (for home and foreign economies, respectively)

$$W_t^D = U^D(C_t^D, H_t^D, \varepsilon_t^D) - \frac{1}{n} \int_0^1 V^D(L_t^D(j), \varepsilon_t^D, \varepsilon_t^L) dj$$  \hspace{1cm} (54)

$$W_t^F = U^F(C_t^F, H_t^F, \varepsilon_t^F) - \frac{1}{n} \int_0^1 V^F(L_t^F(j), \varepsilon_t^F, \varepsilon_t^L) dj$$  \hspace{1cm} (55)

Expression (54) can be approximated by a second-order Taylor series expansion (see appendix C for details), which gives that the welfare function of the home economy is approximately equal to the following expression, depending on variables denoted in terms of log-deviations from the steady state at moment $t$:

$$W_t^D = U^D(C_t^D) + \hat{U}_{C,D}(C_t^D) C_t^D + \frac{1}{2} \left( \hat{C}_t^D - h \hat{C}_t^{D,1} \right)^2 + \frac{1 - h}{2(1 - h)} \hat{C}_t^{D,2} + \frac{1 - h}{2(1 - \sigma_c)} \hat{\varepsilon}_t^D + \frac{1 - h}{2(1 - \eta_c)} \hat{\varepsilon}_t^{D,2} +$$

$$- u_1 \left( \hat{\pi}_t^D - \gamma_p \hat{\pi}_{D,t-1} \right)^2 - u_2 \left( \hat{\pi}_{D,t} - \gamma_p \hat{\pi}_{D,t-1} \right)^2 -$$

$$- u_3 \hat{Y}_t^D + u_4 \hat{Y}_t^D \hat{A}_t^D - u_5 \hat{Y}_t^D \left( 1 + \hat{b}_t^D + \hat{\varepsilon}_t^{D,2} \right) \hspace{1cm} (56)$$

18
where $U^D (C^D)$ is the steady-state utility from consumption, $\bar{U}_{CD} (C^D)$ is the steady-state marginal utility from consumption and $C^D$ is the steady-state consumption level. Take also into account the following simplifying expressions:

\[
\begin{align*}
\dot{w}_{i,t} &= \ddot{w}_{i,t} - \dddot{w}_{i,t-1} \\
u_1 &= \frac{\xi^D \varphi (\varphi \sigma_L + 1) (1 - \Theta)}{2 (1 - \xi_w^D) (1 - \beta \xi_w^D)} \\
u_2 &= \frac{2 (1 - \xi^D) \left( 1 - \beta \xi_w^D (1 + n) \right)}{(1 - \Theta) (1 + n \phi + \sigma_L)} \\
u_3 &= \frac{2 (1 + \phi)^2}{(1 - \Theta) (1 + n \phi - \sigma_L)} \\
u_4 &= \frac{1 - \Theta}{1 + n \phi} \\
u_5 &= 1 - \frac{\theta - 1 \varphi - 1}{\theta}, \text{ which gives the overall degree of inefficiency of the economy.}
\end{align*}
\]

Similarly, we have for the foreign economy:

\[
W^F_t = U^F (C^F) + \bar{U}_{CF} (C^F) C^F 
\]

\[
W_t = nW^D_t + (1 - n) W^F_t 
\]

The first term in brackets in the welfare function (56) shows that agents appreciate that consumption (in terms of deviations from the steady-state) is higher than a share of previous period consumption, i.e., consumers derive utility from habit persistence. Whenever they have the possibility to increase consumption above this habit level, they have welfare gains; when they are not able to maintain consumption at least at the habit level, they have welfare losses. Welfare also depends positively on the correlation between consumption and the preference shock. Whenever a positive preference shock induces an increase in consumption, this is valued positively by agents and there are welfare gains.

On the other hand, agents dislike rapid and large changes in consumption and output, i.e., volatility in their consumption level or in the ability to purchase. Volatility of the change in the consumption from the habit level decreases welfare (\(\frac{\sigma_c}{2 (1 - h)} > 0\)). Volatility in wage and price inflation also leads to welfare losses (\(u_1 > 0\) and \(u_2 > 0\)). However, since there is wage/price rigidity and the
agents that are not able to reoptimize can have their wage/prices reviewed by indexing to previous period producer price inflation, then the more imperfect the indexation the larger the welfare losses will be. Output volatility also counts negatively to the welfare, as agents prefer a smooth income path ($u_3 > 0$). Regarding the correlation of shocks with output, this usually impacts negatively in the agents welfare ($u_4 < 0$ if $1 + n \phi < \sigma_L$ and $u_5 > 0$). There is however one exception: in case $1 + n \phi > \sigma_L$, a positive correlation between the technology shock and output is deemed as positive. The elasticity of work effort with respect to real wage must be sufficiently low in comparison to size and the share of fixed costs over output, so that there can be a positive correlation between output and the technology shock\textsuperscript{10}.

4 The calibrated model

In this section\textsuperscript{11} we describe the behaviour of the model\textsuperscript{12} in response to various shocks: a demand shock (the preferences shock $\tilde{\tau}^b$), two supply shocks (the productivity shock $A_t$ and the labour supply shock $\tilde{\tau}^L$) and a common monetary policy shock ($\tilde{m}_t$). We consider first the case of perfectly symmetric countries, i.e., both economies share the same parameters and show no home bias in consumption ($\varpi = \varpi^* = 0.5$). The countries will also be subject only to common shocks. In this way, we intend to characterize the area wide economy and its behaviour in the presence of shocks. The model is calibrated with parameters values close to the estimates found by Smets and Wouters (2003). Nonetheless, given the general characteristics of the model, it can be applied to any currency area. Later, we consider idiosyncratic shocks and relax the perfect symmetry hypothesis.

Table 1 summarizes the calibration, assuming that the economies are similar. The parameters $c_D$ and $c_F$ are made consistent with the steady-state levels for the calibrated parameters and $\phi^D$ and $\phi^F$ are such that the steady-state profits are null (Christiano et al., 2005).

\textsuperscript{10}In our baseline scenario (Table 1) this case of sufficiently low labour elasticity does not verify and we have $u_4 < 0$.

\textsuperscript{11}We use Dynare running in Matlab for the simulations presented in the paper.

\textsuperscript{12}Equation (1) in Appendix B is not included in the calibrated and simulated model. Given the aggregate equilibrium condition (52), the foreign consumption is obtained as a residual.
Table 1: Parameters values used in the calibration and simulation of the model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.99</td>
</tr>
<tr>
<td>$h$</td>
<td>Consumer persistence</td>
<td>0.6</td>
</tr>
<tr>
<td>$\sigma_c$</td>
<td>Relative risk aversion coefficient on consumption</td>
<td>1.4</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Home bias</td>
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</tr>
<tr>
<td>$\sigma_L$</td>
<td>Relative risk aversion coefficient on labour supply</td>
<td>2.4</td>
</tr>
<tr>
<td>$\gamma_w$</td>
<td>Wage indexation</td>
<td>0.75</td>
</tr>
<tr>
<td>$\xi_w$</td>
<td>Calvo probability on wages</td>
<td>0.7</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Labour demand elasticity</td>
<td>3</td>
</tr>
<tr>
<td>$\gamma_p$</td>
<td>Price indexation</td>
<td>0.5</td>
</tr>
<tr>
<td>$\xi_p$</td>
<td>Calvo probability on prices</td>
<td>0.9</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Price elasticity</td>
<td>6</td>
</tr>
<tr>
<td>$n$</td>
<td>Size of the home economy</td>
<td>0.5</td>
</tr>
<tr>
<td>$\gamma_R$</td>
<td>Interest rate smoothing</td>
<td>0.8</td>
</tr>
<tr>
<td>$\gamma_\pi$</td>
<td>Weight on inflation</td>
<td>1.7</td>
</tr>
<tr>
<td>$\gamma_y$</td>
<td>Weight on output</td>
<td>0.1</td>
</tr>
<tr>
<td>$\gamma_{\Delta\pi}$</td>
<td>Weight on inflation differential</td>
<td>0.15</td>
</tr>
<tr>
<td>$\gamma_{\Delta y}$</td>
<td>Weight on output differential</td>
<td>0.15</td>
</tr>
<tr>
<td>$\rho_B$</td>
<td>Persistence of the preference shock</td>
<td>0.85</td>
</tr>
<tr>
<td>$\rho_L$</td>
<td>Persistence of the labour supply shock</td>
<td>0.89</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>Persistence of the productivity shock</td>
<td>0.82</td>
</tr>
<tr>
<td>$\rho_m$</td>
<td>Persistence of the monetary policy shock</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Size of the preference shock</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Size of the labour supply shock</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Size of the productivity shock</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Size of the monetary policy shock</td>
<td>0.1</td>
</tr>
</tbody>
</table>
4.1 Model dynamics

Figures 2 to 5 show the impulse response functions (i.r.f.) of the aggregate area to the four shocks considered in the model\(^{13}\). Generally, the variables return to the steady-state level in the time span of almost 5 years. Given the aggregate equilibrium condition (52), the evolution of output always equals the path for consumption.

Figure 2: Area wide variables’ impulse responses to a common preference shock ($\xi_b^t$).

The preference shock $\xi_b^t$ is a shock to the discount factor affecting the intertemporal substitution of households. A positive preference shock (Figure 2) increases consumption and output immediately and the maximum deviation from the steady-state is reached 3 quarters after the shock occurred. The increased demand pushes up prices, labour and wages. Inflation deviation is small, but increases until it reaches a maximum one year after the shock was observed. The interest rate reacts immediately to the changes observed in output and inflation, increasing more strongly than inflation and leading to a positive deviation of the real interest rate. The observed response is broadly in line with the literature. For example, Smets and Wouters (2003) show i.r.f.s with a slightly

\(^{13}\)The labels in the charts represent euro area aggregate variables: ‘pi’ for consumer price inflation, ‘Yagg’ for output, ‘c’ for consumption, ‘R’ for the nominal interest rate and ‘L’ for labour supplied. All variables are in percentage deviations from the steady state with the exception of inflation and nominal interest rate which are expressed as percentage point deviation.
higher short run impact, but with similar patterns as the ones above. The maximum effect of the shock is reached in both models around 1 year after the shock is observed.

Figure 3: Area wide variables’ impulse responses to a common labour supply shock ($\xi^L_t$).

A negative labour supply shock reduces the amount of labour that households want to offer to firms, and, therefore, has a negative impact on output and increases production costs (Figure 3). The maximum deviation from the steady state of labour, consumption and output occurs around two years after the shock has been observed. The immediate increase observed in wages is reflected in the increase in area inflation. Given the sluggish behaviour in wages and prices, the maximum impact on inflation is reached one year after the shock was observed. The central bank reacts to the increasing inflation and to the changes in output. However, given the preference for smoothing the interest rate path and given the negative output gap, the real interest rate (not shown in the figures, but equal to $\hat{R}_t - \hat{\pi}_t$) is below the initial level during two years. The impact of a labour supply shock in our framework leads to a slightly weaker response of the variables than what has been observed in other estimated DSGE models of the euro area (e.g. Smets and Wouters, 2003).

Figure 4 shows the i.r.f.s following a positive technology shock. The technology shock leads to an increase in productivity, as firms can produce the same amount of goods at a lower cost. Thus, we observe an immediate decrease of
marginal costs, allowing for the observed increase in output and decrease in prices, which then stimulates consumption. Firms can now produce the same amount of goods with lower input, implying a relevant decrease in labour supply, since households are also willing to reduce the labour supply. However, labour returns to the steady state level around two years later. Monetary policy reacts with some delay to the fall in inflation, given the high preference for smoothing the interest rate path. Also due to this feature, the real interest rate remains positive which refrains the full effect of the shock on production. The response of the model to the productivity shock is quite similar to what we find in Smets and Wouters (2003).

Finally, figure 5 shows the impact of a temporary monetary policy tightening shock. This generates a strong response in a hump-shaped pattern in all variables of the model. The maximum effect is observed during the first year. The higher interest rate motivates consumers to postpone consumption, leading also to the decrease in output in order to respond to the lower demand. Given this, firms need less labour. Nonetheless, at the end of the first year, the economy starts to recover. This is a quicker recovery than what is generally observed in literature (Smets and Wouters, 2003), which identifies a year and a half for the maximum effects to be felt on the same variables as considered here. Output, consumption, labour and the interest rate return to the steady state around 3 years after the shock was observed, while the sluggish behaviour of prices only allows for the return of inflation to the steady state one year later. Comparing
the responses to Smets and Wouters (2003), we observe that our model produces weaker and smoother responses to shocks.\textsuperscript{14}

### 4.2 Welfare and different monetary policy rules

The previous section analysis assumed only one monetary policy rule, a kind of expanded Taylor rule, with features recently used in literature, such as interest rate smoothing and differential component of inflation and output gap (Smets and Wouters, 2003).

We are interested in assessing the impact on countries and the union welfare from having heterogeneity among the monetary union. We also evaluate different policy rules which are specified according to variations of the Taylor rule. In this way, we consider the original rule and seven derivations from this rule:

1. Original rule:
   
   \[
   \hat{R}_t = 0.8 \hat{R}_{t-1} + 0.2 \left(1.7 \hat{\pi}_t + 0.1 \hat{Y}_t\right) + 0.15 (\hat{\pi}_t - \hat{\pi}_{t-1}) + 0.15 \left(\hat{Y}_t - \hat{Y}_{t-1}\right) + \hat{m}_t
   \]

2. Rule without differential component:

\textsuperscript{14}The faster adjustment in our model than in Smets and Wouters (2003) can be due to the inclusion in their model of capital and further rigidities and frictions.
\[ \hat{R}_t = 0.8 \hat{R}_{t-1} + 0.2 \left( 1.7 \hat{\pi}_t + 0.1 \hat{Y}_t \right) + \hat{m}_t \]

3. Rule without smoothing:
\[ \hat{R}_t = 1.7 \hat{\pi}_t + 0.1 \hat{Y}_t + 0.15 \left( \hat{\pi}_t - \hat{\pi}_{t-1} \right) + 0.15 \left( \hat{Y}_t - \hat{Y}_{t-1} \right) + \hat{m}_t \]

4. Basic Taylor rule: \[ \hat{R}_t = 1.7 \hat{\pi}_t + 0.1 \hat{Y}_t + \hat{m}_t \]

5. Low weight on inflation:
\[ \hat{R}_t = 0.8 \hat{R}_{t-1} + 0.2 \left( \hat{\pi}_t + 0.1 \hat{Y}_t \right) + 0.15 \left( \hat{\pi}_t - \hat{\pi}_{t-1} \right) + 0.15 \left( \hat{Y}_t - \hat{Y}_{t-1} \right) + \hat{m}_t \]

6. High weight on inflation:
\[ \hat{R}_t = 0.8 \hat{R}_{t-1} + 0.2 \left( 2 \hat{\pi}_t + 0.1 \hat{Y}_t \right) + 0.15 \left( \hat{\pi}_t - \hat{\pi}_{t-1} \right) + 0.15 \left( \hat{Y}_t - \hat{Y}_{t-1} \right) + \hat{m}_t \]

7. No weight on output gap:
\[ \hat{R}_t = 0.8 \hat{R}_{t-1} + 0.2 \left( 1.7 \hat{\pi}_t \right) + 0.15 \left( \hat{\pi}_t - \hat{\pi}_{t-1} \right) + 0.15 \left( \hat{Y}_t - \hat{Y}_{t-1} \right) + \hat{m}_t \]

8. High weight on output gap:
\[ \hat{R}_t = 0.8 \hat{R}_{t-1} + 0.2 \left( 1.7 \hat{\pi}_t + \hat{Y}_t \right) + 0.15 \left( \hat{\pi}_t - \hat{\pi}_{t-1} \right) + 0.15 \left( \hat{Y}_t - \hat{Y}_{t-1} \right) + \hat{m}_t \]

The first four rules are different rules that the central bank can follow, while the last four rules are variations of the original rule with the purpose of assessing the relevance of the different weights on inflation and the output gap.

Figure 6 below presents the results for the average welfare after simulations of 20,000 periods, considering different sources of heterogeneity among countries and the use by the central bank of the different monetary policy rules. The first column of charts shows the results for the aggregate area, the second column the results for the home economy and the third for the foreign economy.

Note that the welfare expression depends on the steady-state of the economies and the reaction to shocks. Changing the home bias value changes the steady-state welfare level, while changes in nominal rigidity parameters keep the steady-state unchanged. The impacts on welfare presented on figure 6 show the total effect of both the shift in the steady-state and the reaction to shocks.

From the analysis of the terms regarding the log-deviations from the steady-state in the welfare expression, we observe that a change in wage and price rigidity impacts on welfare through two channels: (i) via the parameters in the welfare function, which weigh agents’ preferences regarding consumption, output and inflation stability, and (ii) via the overall system dynamics, especially through the impact on inflation and output volatility. Indeed, a lower nominal rigidity increases inflation volatility in both countries and output volatility in the more rigid country, which impacts negatively on union welfare.

Irrespective of the rule followed by the central bank, higher flexibility (either on wages or prices) in one of the countries (assumed to be the home economy in

\[ \xi_u, \xi_p \] increases the value of parameters \( u_1 \) or \( u_2 \) which weight the volatility of wage or price inflation in the welfare. Therefore, lower nominal rigidity impacts positively on welfare through the lower sensitivity of agents to inflation volatility.

\[ \xi_u, \xi_p \]
the results presented) decreases welfare in both countries. When wages or prices are more flexible at home, welfare is lower in this country than in the foreign country. It should also be mentioned that a very high degree of wage rigidity in the home economy relative to price rigidity has a quite significant negative impact in the home economy’s welfare. When the overall nominal rigidity of the countries is more similar, the union is in the best situation in terms of its welfare.

These results are somehow surprising. One would expect that more flexible economies lead to larger welfare gains for the society. The existence of heterogeneity in a currency union and the fact that the central bank follows a non-optimal rule that does not respond to countries’ specificities can justify these results. Given that nominal rigidities have a significant impact on countries’ welfare, a deeper analysis is performed in the next subsection.

The impact on welfare from different levels in the home bias of the domestic economy is determined by the impacts on the steady-state welfare level and the inflation volatility. Welfare in the home country decreases with the home bias, while in the foreign country the opposite occurs. This pattern is due to the impact in the steady-state levels, since when there is a lower preference for consuming home produced goods, home production is lower and home households supply fewer labour and consume more in comparison to foreign households, which have to produce more of their goods. Additionally, welfare in both countries is at its best level when countries are complementary, i.e., when the aggregate preference of goods is the same for the two countries ($\pi + \pi^* = 1$).\(^{17}\)

Finally, the comparison of the results obtained by applying different policy rules suggests that rules that have a higher weight on inflation and a lower weight on the output gap provide the best result regarding welfare, which is in line with the literature. Rules that weigh more the output gap or less the inflation rate lead to the detached welfare curves observed in figure 6. In this way, the central bank should react more strongly to inflation deviations around the target than to the output gap. When comparing the different rules according to their structure (rules 1 to 4), we observe that the impact on welfare is very similar among these rules. Then, the choice of the central bank among different formulations of rules is not relevant.

The major determinant of the ranking of the policy rules according to their impact on welfare is inflation volatility. Indeed, rules with a higher weight on the inflation target and a lower weight on the output gap allow a greater stabilization of inflation. On the other hand, these rules lead to larger volatility of output and labour. It should also be mentioned that rules with a larger weight on the output gap and rules without interest rate smoothing generate larger volatility in the interest rate. These results are also in line with what would be expected and with the literature.

\(^{17}\)In the simulations presented in figure 6 this occurs when the home bias in the domestic economy is equal to 0.5, the same level as in the foreign economy.
Figure 6: Welfare analysis considering different policy rules and different parameter values.
4.3 The importance of nominal rigidity and country heterogeneity

From figure 6 we obtained some surprising results, as higher price and wage flexibility in the home country reduces welfare, since one would expect that the more flexible the economies are, the better the welfare would be.

However, our analysis suggests that in a monetary union, where the common central bank responds only to aggregate variables, what matters most for welfare is the overall level of rigidity in the economy and the similarities between countries\textsuperscript{18}.

Figure 7 shows the results of the simulations for the welfare log-deviations from the steady-state of both countries and the aggregate. Countries remain equal at all times, which means that rigidity parameters change at the same time in both countries. When both countries are flexible, regarding wages and prices, welfare losses are at a minimum value. Therefore, as it would be expected, nominal flexibility is indeed the best situation for both countries. As wage and price rigidity increases, welfare losses also rise. If countries start from a flexible situation and increase their rigidity, welfare diminishes, and the losses are stronger and more pronounced when only wage rigidity increases. On the other hand, when countries start from the baseline scenario (sticky wages and prices), welfare does not change significantly when wages get more flexible, but it decreases strongly as price setting becomes increasingly flexible. Then, from this analysis, one can conclude first, that increasing the overall flexibility of the union improves welfare, and second, that price flexibility without wage flexibility is not desirable from a welfare viewpoint, as price inflation is more important for welfare than wage inflation.

The analysis also allows us to conclude that a situation where overall the\textsuperscript{18}The results and conclusions presented in this section are based on simulations with the central bank following rule 1 and with the remaining parameters equal to the baseline scenario. We have also compared different policy rules, but the conclusions regarding rules hierarchy do not change.
economies are very sticky is almost equivalent to a situation with a very low degree of nominal rigidity. This is because in a high rigidity scenario there is almost no variability in the economy. However, this is only valid when countries are equal.

Indeed, it is quite important for societies’ welfare that the economies are similar. From figure 8 we can observe that welfare losses are minimized when there is more homogeneity in the currency union. When the foreign country remains unchanged from the baseline scenario, increasing only price flexibility in the home economy increases welfare losses in both countries and, curiously, these losses are stronger in the home country. Increasing only wage flexibility domestically does not significantly change welfare in both countries. But increasing overall flexibility in the home country improves welfare domestically but in the foreign economy it gets much worse.

On the other hand, when the union is flexible and the home economy increases its rigidity, the foreign country welfare remains broadly unchanged. However, in the home economy welfare is worsened by the increased price and wage rigidity, with wage rigidity worsening welfare the most.

Figure 8: Welfare analysis for different degrees of nominal rigidity of the home economy, while the foreign remains unchanged.

All in all, we find out that if countries are rigid in their price and wage setting, in a currency union where the central bank responds to the aggregate and does not take into account national differences, then it is preferable to increase flexibility in both countries and in both wages and prices. If one country attempts to increase flexibility of its wages or prices without cooperating with the other country, the overall welfare decreases. As labour markets are specific to each country, making only wages more flexible does not significantly change welfare. However, increasing price setting flexibility while wages are sluggish in labour markets without mobility worsens significantly the area wide welfare, given that more adjustments are made through prices and price inflation weighs more in the welfare than wage inflation.

It should be mentioned that the above results are obtained in a model without government, and these may change if we include fiscal policy. Adão et al.
(2006) study the ability of fiscal policy to accommodate specific shocks in a currency union. They conclude that fiscal policy can fully accommodate specific shocks as long as there is no labour mobility within the union. In case labour can move between countries, then it is not possible to replicate the set of allocations under flexible prices.

Additionally, it should be taken into consideration that these conclusions are taken assuming that the central bank does not change the monetary policy rule when the parameters change, and that the results are dependent of the shocks considered. Adão et al. (2003) shows that in a currency union with only one friction and in face of common shocks, the optimal monetary policy is able to replicate the full flexibility allocation.

4.4 Nominal rigidities and country weights in the policy rule

The analysis in the previous section was conducted assuming that the central bank does not follow an optimal rule but a simple ah-hoc rule instead. This can be justified on the grounds that simple rules seem to be a good proxy to optimal rules (Galí, 2002) and are better understood by economic agents. However, one could also consider the case when the central bank takes into account the economies’ specificity, which could lead to a better result regarding welfare. For instance, Benigno (2004) defends that the optimal monetary policy in a currency union where there are differences in price rigidity among countries can be approximated by an inflation targeting policy rule which gives a higher weight to inflation in the more rigid country.

Following the conclusion of Benigno (2004), we could ask what would be the impact on welfare if the central bank weighted each country differently, instead of according to their size. Would it be better for the union if the central bank gave a higher weight to inflation in the more rigid country? In this way, we will perform simulations on our model, simplifying the original rule by excluding the differential components and assuming that the central bank can weigh each country’s variables with a weight different from the population size, i.e., the central bank will follow the rule:

\[
\hat{R}_t = \gamma_R \hat{R}_{t-1} + (1 - \gamma_R) \left[ \gamma_\pi \left( n^{CB} \pi^{CD}_t + (1 - n^{CB}) \pi^{CF}_t \right) + \gamma_y \left( n^{CB} \hat{Y}^{CD}_t + (1 - n^{CB}) \hat{Y}^{CF}_t \right) \right] + \hat{m}_t
\]

This exercise allows us to conclude that the central bank can achieve a better result in terms of the union welfare if it gives more importance to the more rigid country. In figure 9 we plot the welfare for the union when changing wage and price rigidity in the home economy and the weight attached to the home country in the policy rule, assuming that the foreign economy remains unchanged at the baseline scenario. When the home country overall nominal rigidity degree is low, it is preferable for the union if the central bank considers almost exclusively inflation and output gap developments in the foreign economy. When countries are similar, then the weight that minimizes welfare losses is near to the real country’s size. However, when the domestic economy is very rigid, then the

\[\text{The parameters of the policy rule will be calibrated according to Table 1 while the central bank will evaluate the different possibilities for the } n^{CB}.\]
central bank should take more into consideration what occurs in this economy. If the central bank would adopt this criteria, this would be also the policy that would induce lower welfare losses for each country taken individually.

Figure 9: Union welfare when changing the wage and price rigidities parameters simultaneously and the weight of the home economy in the policy rule.

When countries are heterogeneous regarding only one of the sources of nominal rigidities, the broad conclusion still applies. Indeed, when only price rigidity differs between countries, the central bank should weigh more inflation and the output gap in the more rigid country in order to reduce the welfare losses for the area wide. However, this would mean that the foreign country, which remains unchanged from the baseline scenario, could be worse in terms of welfare, as it has lower welfare losses when the central bank weighs the countries closely to the true size for every level for the Calvo-price parameter in the domestic economy.

In the case of only wage rigidity heterogeneity, the central bank should also weigh more in its decisions the more rigid country, but the weight is closer to the true size of the countries than when there is price stickiness heterogeneity. This difference might be related to the fact that labour markets are not so free to adjust since there is no labour mobility between countries. If the central bank would take these differences into consideration, then it would also improve the welfare in the home economy, but for the foreign country the impact is small.
5 Conclusions

The main purpose of this paper was to study the effects of having heterogeneous countries sharing the same currency and monetary policy. The motivation comes from the acknowledgement of persistently different behaviors and outcomes between euro area countries. Given that the Eurosystem’s monetary policy responds to the euro area wide inflation, countries’ idiosyncrasies do not count for policy definition.

In this context, we built a two-country DSGE model, which includes several common features of this type of model: habit formation, product and labour differentiation, monopolistic competition and price and wage rigidity. In addition, there is no labour mobility between the two countries and consumers can have different preferences for home and foreign produced goods. Countries can diverge regarding various features, but in this paper we considered that they could be different regarding the home bias and the wage and price rigidity. Although each possible source of country differentiation is treated in an isolated fashion, the paper assesses the impact of more sources of heterogeneity than the current literature, as far as to our knowledge.

The model is calibrated for replicating the euro area wide behaviour and is found to be able to reproduce the response of the economy to shocks relatively closer to Smets and Wouters (2003).

Regarding welfare assessment, nominal rigidity is found to be an important source of heterogeneity. In a currency union where the central bank responds to the aggregate and does not take into account national differences, then it is preferable to increase flexibility in both countries and in both wages and prices, when the starting point is the rigid scenario. There are significant welfare losses when only one country attempts to increase the flexibility of its wage or price setting or when countries attempt to make only wages or prices more flexible. These losses are more prominent when countries promote price flexibility with rigidity on wage setting in a currency union without labour mobility. If the central bank can observe each country’s nominal rigidities levels, then it would have significant welfare improvements if it attached more importance to inflation and output gap evolution in the more rigid country, which is true even when the central bank follows a simple ad-hoc policy rule.

One line of possible future research would follow from this last conclusion regarding the evaluation of policy response. In this way, it would be interesting to understand what would be the optimal policy of the central bank. On another line of research, we can speculate whether allowing for labour mobility would change the importance of wage sluggishness in welfare. One could expect that if labour could move between countries, we would have one more mean of adjustment to shocks and countries with more rigid wages could have higher welfare losses. Therefore, allowing for labour mobility is one of the interesting possible lines of future research. However, Adão et al. (2006) have shown that in a currency union with sticky prices, fiscal policy is able to offset the impact of asymmetric shocks as long as labour can not move between countries.

Additionally, the model could also be enriched by introducing capital, freely moving inside the area, and fiscal policy, independently set by each country. These two features would bring our model closer to the euro area’s reality. Finally, it would also be interesting to follow a different line of research by estimating the model for one country, namely Portugal, while the foreign coun-
terpart of the model could be the remaining euro area, as Pytlarczyk (2005) has done for Germany. This could also be useful for analyzing the possible effects of the common monetary policy in Portugal.
A Appendix - The steady-state model

In this appendix, the expression of the model in the steady-state are presented. The solution is not explicitly stated given its non-linearity, but one can prove that the steady-state is unique and stable given the calibration used in the dissertation.

1. Rate of return on bonds
   \[ R = \frac{1}{\beta} \]

2. Real wage
   \[ \bar{w}_D = \frac{\varphi}{\varphi - 1} \left( \frac{L^D}{[D^C (1 - h)]} \right)^{-\sigma} \]
   \[ \bar{w}_F = \frac{\varphi^*}{\varphi^* - 1} \left( \frac{L^F}{[F^C (1 - h^*)]} \right)^{-\sigma} \]

3. Production function
   \[ \phi^D = \frac{L^D}{Y^D} \]
   \[ \phi^F = \frac{L^F}{Y^F} \]

4. Fixed costs
   \[ \phi^D = 1 + \frac{1}{\theta} \]
   \[ \phi^F = 1 + \frac{1}{\theta^*} \]

5. Marginal cost
   \[ mc^D = \frac{\theta - 1}{\theta} \]
   \[ mc^F = \frac{\theta^* - 1}{\theta^*} \]

6. Marginal productivity
   \[ 1 = \frac{\varphi}{\varphi - 1} \frac{\theta}{\theta - 1} \left( \frac{L^D}{[D^C (1 - h)]} \right)^{-\sigma} \]
   \[ 1 = \frac{\varphi^*}{\varphi^* - 1} \frac{\theta^*}{\theta^* - 1} \left( \frac{L^F}{[F^C (1 - h^*)]} \right)^{-\sigma} \]

7. Optimal price
   \[ P_D = \bar{P}_D \]
   \[ P_F = \bar{P}_F \]

8. Price parity
   \[ \frac{P^c_D}{P^c_F} = \left( \frac{P_D}{P_F} \right)^{z - z^*} \]
9. Terms of trade
\[ T = 1 \]

10. Market equilibrium
\[ Y^D = \omega C^D + \frac{1-n}{n} \omega^* C^F \]
\[ Y^F = (1-\omega) \frac{n}{1-n} C^D + (1-\omega^*) C^F \]

11. Aggregate economy
\[ Y = C \]

B Appendix - Equations for the foreign economy in the log-linearized model

1. Consumption equation
\[ \hat{C}_t = \frac{h^*}{1+h^*} \hat{C}_{t+1} + \frac{1}{1+h^*} E_t \hat{C}_{t+1} + \frac{1-h^*}{\sigma_z^2 (1+h^*)} (\tilde{\beta}^F - E_t \tilde{\beta}^F) - \frac{1-h^*}{\sigma_z^2 (1+h^*)} (\hat{R}_t - E_t \hat{s}^F_{t+1}) \]

2. Preference shock
\[ \tilde{\beta}^F = \rho \tilde{\beta}^F_{t+1} + \xi_t^F \]

3. Real wage
\[ \hat{w}_{F,t} = \frac{\beta}{1+\beta} E_t \hat{w}_{F,t+1} + \frac{1}{1+\beta} \hat{w}_{F,t-1} + \frac{\beta}{1+\beta} E_t \hat{w}_{F,t+1} - \frac{1}{1+\beta} \gamma_w^* \hat{w}_{F,t} + \gamma_w^* \hat{w}_{F,t-1} - \frac{1}{1+\beta} \left( 1 - \beta \xi_w^F \right) \left( 1 - \xi_w^F \right) \left[ \hat{w}_{F,t} - \sigma_L^F \hat{L}_{t}^F - \frac{\sigma_u^*}{1-h^*} \left( \hat{C}_t^F - h^* \hat{C}_{t-1}^F \right) - \tilde{z}_t^F \right] \]

4. Labour supply shock
\[ \tilde{z}_t^F = \rho \tilde{z}_{t+1}^F + \xi_t^F \]

5. Producer price inflation
\[ \hat{\pi}_{F,t} = \frac{\beta}{1+\beta} E_t \hat{\pi}_{F,t+1} + \frac{\gamma_p^*}{1+\beta \gamma_p^*} \hat{\pi}_{F,t-1} + \frac{1}{1+\beta \gamma_p^*} \left( 1 - \beta \xi_p^F \right) \left( 1 - \xi_p^F \right) \left( \hat{w}_{F,t} - \hat{A}_t^F \right) \]

6. Productivity shock
\[ \hat{A}_t^F = \rho \hat{A}_{t+1}^F + \hat{\eta}_{a,t}^F \]

7. Consumer price inflation
\[ \hat{\pi}_t^C = \omega^* \hat{\pi}_{D,t} + (1 - \omega^*) \hat{\pi}_{F,t} \]

8. Aggregate production function
\[ \hat{Y}_t^F = \phi^F \left( \hat{A}_t^F + \hat{L}_t^F \right) \]

9. Market clearing
\[ \hat{Y}_t^F = (1-\omega) \frac{n}{1-n} T^- \frac{C^D}{Y^F} \left( -\omega T_t + \hat{C}_t^F \right) + (1-\omega^*) T^- \frac{C^F}{Y^F} \left( -\omega^* T_t + \hat{C}_t^F \right) \]
C Appendix - Determination of the welfare function

The determination of the welfare expression follows the methods for the approximation of loss functions discussed in Woodford (2003) and Benigno and Woodford (2004). The average utility of the representative household at moment $t$ is given by:

$$W_t = U(C_t, H_t, \xi^t) - \frac{1}{n} \int_0^n V(L_t(i), \xi^i_t, \xi^t)\,di$$  \hspace{1cm} (60)

where: $U(C_t, H_t, \xi^t) = \frac{1}{1 - \sigma_c} (C_t - H_t)^{1 - \sigma_c}$ is the utility from consumption and $V(L_t(i), \xi^i_t, \xi^t) = \frac{E}{1 + \sigma_t} L_t(i)^{1 + \sigma_t}$ is the disutility from working, and both are defined from the utility expression (2).

C.1 Approximation of the utility from consumption

Following Woodford (2003), we now compute a quadratic Taylor series approximation to (60). First, we get the following result for the second-order Taylor expansion of $U(C_t, H_t, \xi^t)$ around the steady state $U = U(C, H, \xi^c)$:

$$U(C_t, H_t, \xi^t) \approx \hat{U} + \hat{U}_C \hat{C}_t + \hat{U}_H \hat{H}_t + \hat{U}_{\xi C} \hat{\xi}_t^C + \frac{1}{2} \hat{U}_{CC} \hat{C}_t^2 + \frac{1}{2} \hat{U}_{HC} \hat{H}_t \hat{C}_t + \frac{1}{2} \hat{U}_{\xi C} \hat{\xi}_t^C \hat{C}_t + \hat{U}_{HH} \hat{H}_t^2 + \hat{U}_{\xi H} \hat{\xi}_t^C \hat{H}_t + \hat{U}_{\xi H} \hat{\xi}_t^C \hat{H}_t + \hat{U}_{\xi \xi} \hat{\xi}_t^C \hat{\xi}_t^C + \mathcal{O} \left( \| \xi \|^3 \right)$$

where a variable with a til means its deviation from the steady state ($\hat{x}_t = x_t - x$) and $\mathcal{O} \left( \| \xi \|^3 \right)$ denotes the order of the residual and $\| \xi \|^2$ is a bound on the amplitude of exogenous disturbances. Substituting in the above expression $\hat{x}_t$ for $\hat{x}_t$ using a Taylor series expansion $\frac{x_t}{x} = 1 + \hat{x}_t + \frac{1}{2} \hat{x}_t^2 + \mathcal{O} \left( \| \xi \|^3 \right)$ (where $\hat{x}_t = \ln x_t - \ln x$), it yields:

$$U(C_t, H_t, \xi^t) \approx \hat{U} + \hat{U}_C \hat{C}_t \left( \hat{C}_t + \frac{1}{2} \hat{C}_t^2 \right) + \hat{U}_H \hat{H}_t \left( \hat{H}_t + \frac{1}{2} \hat{H}_t^2 \right) + \hat{U}_{\xi C} \hat{\xi}_t^C \left( \hat{\xi}_t^C + \frac{1}{2} \hat{\xi}_t^C \hat{C}_t \right) + \frac{1}{2} \hat{U}_{CC} \hat{C}_t^2 \hat{C}_t^2 + \frac{1}{2} \hat{U}_{HC} \hat{H}_t \hat{C}_t \hat{C}_t + \frac{1}{2} \hat{U}_{\xi C} \hat{\xi}_t^C \hat{\xi}_t^C \hat{C}_t + \hat{U}_{HH} \hat{H}_t^2 \hat{H}_t^2 + \mathcal{O} \left( \| \xi \|^3 \right)$$

Derivating, we have:

$$\hat{U}_C = \varepsilon^b (C - H)^{-\sigma_c}$$
$$\hat{U}_H = -\varepsilon^b (C - H)^{-\sigma_c} = -\hat{U}_C$$
$$\hat{U}_{\xi C} = \frac{1}{1 - \sigma_c} (C - H)^{1 - \sigma_c} = \frac{1 - \sigma_c}{1 - \sigma_c} \hat{U}_C$$
$$\hat{U}_{CC} = -\sigma_c \varepsilon^b (C - H)^{-\sigma_c - 1} = \frac{-\sigma_c}{(C - H)} \hat{U}_C$$
$$\hat{U}_{HH} = -\sigma_c \varepsilon^b (C - H)^{-\sigma_c - 1} = \frac{-\sigma_c}{(C - H)} \hat{U}_C$$
$$\hat{U}_{\xi \xi} = 0$$
$$\hat{U}_{\xi H} = \sigma_c \varepsilon^b (C - H)^{-\sigma_c - 1} = \frac{\sigma_c}{(C - H)} \hat{U}_C$$
$$\hat{U}_{\xi \xi} = \frac{1}{\varepsilon^b} \hat{U}_C$$
$$\hat{U}_{HH} = -\sigma_c (C - H)^{-\sigma_c} = -\frac{1}{\varepsilon^b} \hat{U}_C$$

37
Replacing $H_t = hC_{t-1}$ yields

$$U(C_t, H_t, \phi_{t-1}^C) \approx \tilde{U} + \tilde{U} C C \left[ \left( \hat{C}_t - h\hat{C}_{t-1} \right) + \frac{1}{2} \left( \hat{C}_t^2 - h^2\hat{C}_{t-1}^2 \right) + \frac{1}{2(1-\sigma_c)} \hat{\sigma}_t^2 - \frac{\sigma_c}{2(1-h)} \left( \hat{C}_t - h\hat{C}_{t-1} \right)^2 + \hat{\sigma}_t \left( \hat{C}_t - h\hat{C}_{t-1} \right) \right] + \mathcal{O} \left( \|\xi\|^3 \right)$$

C.2 Approximation of the disutility from working

If we integrate the disutility from working over the population of the economy, we get

$$\frac{1}{n} \int_0^n V(L_t(i), \xi^b_t, \xi^c_t) di = \frac{1}{n} \int_0^n \frac{\varepsilon^b_t}{1 + \sigma_t} L_t(i) \left( \frac{W_t(i)}{L_t} \right)^{-\varphi} \left( \frac{L_t}{n} \right)^{1+\varphi_L} di \Rightarrow$$

$$\frac{1}{n} \int_0^n V(L_t(i), \xi^b_t, \xi^c_t) di = \frac{\varepsilon^b_t}{1 + \sigma_t} L_t \left( \frac{W_t(i)}{W_t} \right)^{-\varphi(1+\varphi_L)} di \Rightarrow$$

$$\frac{1}{n} \int_0^n V(L_t(i), \xi^b_t, \xi^c_t) di = \frac{\varepsilon^b_t}{1 + \sigma_t} \left( \frac{L_t}{n} \right)^{1+\varphi_L} \Delta_{w,t} = V(L_t, \xi^b_t, \xi^c_t) \Delta_{w,t}$$

given equation (12). The variable $\Delta_{w,t} = \int_0^n \left( \frac{W_t(i)}{W_t} \right)^{-\varphi(1+\varphi_L)} di$ denotes the measure of wage dispersion at date $t$ (see Benigno and Woodford, 2004).

The approximation of $V(L_t, \xi^b_t, \xi^c_t) \Delta_{w,t}$ follows Benigno and Woodford (2004):

$$V(L_t, \xi^b_t, \xi^c_t) \Delta_{w,t} = \tilde{V} + \tilde{V} \left( \Delta_{w,t} - 1 \right) + \tilde{V}_{LL} \tilde{L}_t + \tilde{V}_{L} \left( \Delta_{w,t} - 1 \right) \tilde{L}_t + \tilde{V}_{L} \tilde{c}_t \left( \Delta_{w,t} - 1 \right) + \tilde{V}_{L} \tilde{e}_t \left( \Delta_{w,t} - 1 \right) + \tilde{V}_{L} \tilde{e}_t \tilde{c}_t \left( \Delta_{w,t} - 1 \right) + \tilde{V}_{L} \tilde{e}_t \tilde{c}_t \tilde{e}_t \left( \Delta_{w,t} - 1 \right) + \tilde{V}_{L} \tilde{e}_t \tilde{e}_t \tilde{e}_t + \tilde{V}_{L} \tilde{e}_t \tilde{c}_t \tilde{e}_t + \tilde{V}_{L} \tilde{c}_t \tilde{e}_t \tilde{e}_t + \mathcal{O} \left( \|\xi\|^3 \right)$$

Derivating $V(.)$, we have:

$$\tilde{V}_L = \frac{\varepsilon^b_t}{n} \left( \frac{L}{n} \right)^{\sigma_L} \Delta_w = \frac{\varepsilon^b_t}{n} \left( \frac{L}{n} \right)^{\sigma_L} \tilde{V}_L$$

$$\tilde{V}_{\xi^b_t} = \frac{\varepsilon^b_t}{1 + \sigma_L} \left( \frac{L}{n} \right)^{1+\sigma_L} \Delta_w = \left( \frac{L}{n} \right)^{1+\sigma_L} \tilde{V}_L$$

$$\tilde{V}_{\xi^c_t} = \frac{\varepsilon^c_t}{1 + \sigma_L} \left( \frac{L}{n} \right)^{1+\sigma_L} \Delta_w = \left( \frac{L}{n} \right)^{1+\sigma_L} \tilde{V}_L$$

$$\tilde{V}_{\xi^b_t \xi^c_t} = \frac{\varepsilon^b_t \varepsilon^c_t}{n^2} \left( \frac{L}{n} \right)^{\sigma_L-1} \Delta_w = \frac{\sigma_L}{L} \tilde{V}_L$$

$$\tilde{V}_{\xi^b_t \xi^c_t} = 0$$

$$\tilde{V}_{\xi^b_t \xi^c_t} = 0$$

$$\tilde{V}_{\xi^b_t \xi^c_t} = \frac{\varepsilon^b_t}{n} \left( \frac{L}{n} \right)^{\sigma_L} \Delta_w = \frac{1}{\varepsilon^b_t} \tilde{V}_L$$

$$\tilde{V}_{\xi^b_t \xi^c_t} = \frac{\varepsilon^b_t}{n} \left( \frac{L}{n} \right)^{\sigma_L} \Delta_w = \frac{1}{\varepsilon^b_t} \tilde{V}_L$$

given that in the steady state there is no price dispersion, so that $\Delta_w = 1$.

Replacing the derivatives in the equation $V(L_t, \xi^b_t, \xi^c_t) \Delta_{w,t}$ and taking into account that the deviations from the steady state of the variables in levels can be approximated by a second-order expansion in terms of the deviations from the steady state of the variables in logs, i.e., $\tilde{x}_t = \tilde{x}_t + \frac{1}{2} \tilde{x}_t^2$, then we have

$$V(L_t, \xi^b_t, \xi^c_t) \Delta_{w,t} = \tilde{V} + \tilde{V} \left( \Delta_{w,t} + \frac{1}{2} \Delta_{w,t}^2 \right) + \tilde{V}_{LL} \left( \tilde{L}_t + \frac{1}{2} \tilde{L}_t^2 \right) + \tilde{V}_L \left( \Delta_{w,t} + \frac{1}{2} \Delta_{w,t}^2 \right) \times$$
In order to determine the law of motion of the wage dispersion measure, we can

C.2.1 Approximation of the wage dispersion measure

One period earlier we have:

\[ \Delta_{w,t-1} = (1 - \xi_w) \left( \frac{W^*_t}{W_{t-1}} \right)^{- \varphi(1+\sigma_L)} - \varphi(1+\sigma_L) \]

\[ + \sum_{j=1}^{\infty} \xi_w^j (1 - \xi_w) \left( \frac{W^*_t \prod_{i=1}^{j} \gamma_{t-i}}{W_t} \right)^{- \varphi(1+\sigma_L)} \]

\[ \Leftrightarrow \]

The result above was obtained taking into consideration that \( \hat{\Delta}_{w,t} \) is of second-order.
\( \Delta_{w,t-1} = (1 - \xi_w) \left( \frac{W^*_{t-1}}{W_t} \right)^{\varphi(1+\sigma_L)} - \left( \frac{W_t}{W_{t-1}} \right)^{\varphi(1+\sigma_L)} + \right.

\left. + \sum_{j=1}^{\infty} \xi_w^j (1 - \xi_w) \left( \frac{W^*_{t-1-j} \prod_{j=1}^{j} \pi_{t-1-i}^w}{W_t} \right)^{\varphi(1+\sigma_L)} \right) \left( \frac{W_t}{W_{t-1}} \right)^{-\varphi(1+\sigma_L)} \right) \)

\( \Delta_{w,t-1} = (1 - \xi_w) \left( \frac{W^*_{t-1}}{W_t} \right)^{\varphi(1+\sigma_L)} - \left( \frac{W_t}{W_{t-1}} \right)^{\varphi(1+\sigma_L)} + \right.

\left. + \sum_{j=1}^{\infty} \xi_w^j (1 - \xi_w) \left( \frac{W^*_{t-1-j} \prod_{j=1}^{j} \pi_{t-1-i}^w}{W_t} \right)^{\varphi(1+\sigma_L)} \right) \left( \frac{W_t}{W_{t-1}} \right)^{-\varphi(1+\sigma_L)} \right)

where \( \pi_{w,t-1} \) is the rate of change of wages \( \pi_{w,t-1} = \frac{W_t}{W_{t-1}} \). Now, multiply \( \Delta_{w,t-1} \) by \( \xi_w, (\pi_{w,t-1})^{\varphi(1+\sigma_L)} \) and \( \pi_{t-1}^{-\gamma_w \varphi(1+\sigma_L)} \).

\( \xi_w (\pi_{w,t-1})^{\varphi(1+\sigma_L)} \pi_{t-1}^{-\gamma_w \varphi(1+\sigma_L)} \Delta_{w,t-1} = \xi_w (1 - \xi_w) \left( \frac{W^*_{t-1}}{W_t} \right)^{\varphi(1+\sigma_L)} + \right.

\left. + \xi_w \sum_{j=1}^{\infty} \xi_w^j (1 - \xi_w) \left( \frac{W^*_{t-1-j} \prod_{j=1}^{j} \pi_{t-1-i}^w}{W_t} \right)^{\varphi(1+\sigma_L)} \right) \left( \frac{W_t}{W_{t-1}} \right)^{-\varphi(1+\sigma_L)} \right)

The right-hand side of the above expression is equal to the second term of the right-hand side of equation (62). Therefore, we get:

\( \Delta_{w,t} = (1 - \xi_w) \left( \frac{W^*_{t}}{W_t} \right)^{\varphi(1+\sigma_L)} + \xi_w (\pi_{w,t})^{\varphi(1+\sigma_L)} \pi_{t-1}^{-\gamma_w \varphi(1+\sigma_L)} \Delta_{w,t-1} \) (63)

From equation (14), we can define the ratio \( \frac{W^*_{t}}{W_t} \) and then replace in equation (63):

\( W_t^{1-\varphi} = \xi_w \left[ \frac{W_{t-1} \pi_{t-1}^{w_{t-1}}}{W_t} \right]^{1-\varphi} + (1 - \xi_w) \left( \frac{W^*_t}{W_t} \right)^{1-\varphi} \Rightarrow \)

\( 1 = \xi_w \left[ \frac{W_{t-1} \pi_{t-1}^{w_{t-1}}}{W_t} \right]^{1-\varphi} + (1 - \xi_w) \left( \frac{W^*_t}{W_t} \right)^{1-\varphi} \Rightarrow \)

\( (1 - \xi_w) \left( \frac{W^*_t}{W_t} \right)^{1-\varphi} = 1 - \xi_w \pi_{w,t-1} \pi_{t-1}^{-\gamma_w \varphi(1-\varphi)} \Rightarrow \)

\( \frac{W^*_t}{W_t} \left[ \frac{1 - \xi_w \pi_{w,t-1} \pi_{t-1}^{-\gamma_w \varphi(1-\varphi)} \left( \frac{1}{\varphi} \right)^{\varphi}}{1 - \xi_w} \right] \)

And finally we get
\[ \Delta_{w,t} = \xi_w (\pi_{w,t})^{(1+\sigma_L)} \pi_{t-1}^{-\gamma_w} \varphi(1+\sigma_L) \Delta_{w,t-1} + (1 - \xi_w) \left[ 1 - \xi_w \pi_{w,t}^{-\gamma_w} \frac{(1 - \gamma_w)(1+\varphi)}{1 - \xi_w} \right] \]

We now take a second-order Taylor approximation of (64).

\[ \Delta_{w,t} = \frac{\partial \Delta_{w,t}}{\partial \pi_w} \pi_{w,t} + \frac{\partial \Delta_{w,t}}{\partial \pi_t} \pi_{t-1} + \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} \pi_{w,t} \pi_{t-1} + \frac{1}{2} \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w^2} \pi_{w,t}^2 + \frac{1}{2} \frac{\partial^2 \Delta_{w,t}}{\partial \pi_t^2} \pi_{t-1}^2 + \]

\[ + \frac{1}{2} \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} \pi_{w,t} \pi_{t-1} + \frac{1}{2} \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} \pi_{w,t} \pi_{t-1} + \frac{1}{2} \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} \pi_{w,t} \pi_{t-1} + \]

\[ + \frac{1}{2} \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} \pi_{w,t} \pi_{t-1} \]

\[ \mathcal{O} \left( \left\| \xi \right\|^3 \right) \]

\[ \frac{\partial \Delta_{w,t}}{\partial \pi_w} = 0 \]

\[ \frac{\partial \Delta_{w,t}}{\partial \pi_t} = 0 \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} = \xi_w \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w^2} = \frac{\varphi(1+\sigma_L)(\varphi\sigma_L+1)}{1 - \xi_w} \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_t^2} = \frac{\gamma_w \varphi(1+\sigma_L)(\varphi\sigma_L+1)}{1 - \xi_w} \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} = 0 \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} = -\gamma_w \varphi(1+\sigma_L)(\varphi\sigma_L+1) \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} = \xi_w \varphi(1+\sigma_L) \]

\[ \frac{\partial^2 \Delta_{w,t}}{\partial \pi_w \partial \pi_t} = -\xi_w \gamma_w \varphi(1+\sigma_L) \]

Using the derivatives and replacing the variables with a til for the deviations from the steady state in logs, we reach

\[ \hat{\Delta}_{w,t} = \xi_w \hat{\Delta}_{w,t-1} + \frac{1}{2} \varphi(1+\sigma_L)(\varphi\sigma_L+1) \frac{\xi_w}{1 - \xi_w} \left( \hat{\pi}_{w,t}^2 + \gamma_w \hat{\pi}_{t-1}^2 - 2\gamma_w \hat{\pi}_{w,t} \hat{\pi}_{t-1} \right) \]

\[ + \mathcal{O} \left( \left\| \xi \right\|^3 \right) \]

This result takes note of the fact that \( \hat{\Delta}_{w,t} \) is already a term of second-order.

### C.2.2 Approximation of aggregate labour and price dispersion measure

Consider the variable \( \Delta_{p,t} = \int_0^p \left( \frac{P_t(i)}{P_i} \right)^{-\theta} \) as the price dispersion measure. Recall equation (10):

\[ L_t = \left[ \frac{1}{\varphi} \int_0^p \nu_t(i) \frac{L_{i-1}}{\nu_{i-1}} \right]^{\frac{1}{\varphi-1}} \]

By equation (18), we can define the individual labour and replace in the expression for the aggregate labour:
\[ Y_t(i) = A_t l_t(i) - \Phi \leftrightarrow l_t(i) = \frac{Y_t(i) + \Phi}{A_t} \]

\[ L_t = \left[ \frac{1}{n} \int_0^n \left( \frac{Y_t(i) + \Phi}{A_t} \right)^{\frac{q-1}{q}} di \right]^{\frac{1}{q-1}} \]

\[ L_t = \left[ \frac{1}{n} \int_0^n \left( \frac{P_t(i)}{P_t} - \Theta \frac{Y_t}{nA_t} + \Phi \frac{A_t}{A_t} \right) di \right]^{\frac{1}{q-1}} \]

by equation (19). By Hölder’s inequality\(^{20}\), we get

\[ \left[ \int_0^n \left( \frac{P_t(i)}{P_t} - \Theta \frac{Y_t}{nA_t} + \Phi \frac{A_t}{A_t} \right) di \right]^{\frac{1}{q-1}} \leq \left[ f_0^n \left( \frac{P_t(i)}{P_t} - \Theta \frac{Y_t}{nA_t} + \Phi \frac{A_t}{A_t} \right) di \right]^{\frac{1}{q-1}} = \int_0^n \left( \frac{P_t(i)}{P_t} - \Theta \frac{Y_t}{nA_t} + \Phi \frac{A_t}{A_t} \right) di \times n^{\frac{1}{q-1}} \]

Consequently,

\[ L_t \leq \left( \frac{1}{n} \int_0^n \left( \frac{P_t(i)}{P_t} \right)^{\frac{q-1}{q}} di \right)^{\frac{1}{q-1}} \frac{Y_t}{A_t} \int_0^n \frac{P_t(i)}{P_t} \frac{Y_t}{nA_t} + \Phi \frac{A_t}{A_t} \]

\[ L_t = c \left( \frac{Y_t}{A_t} \Delta_p + \frac{n\Phi}{A_t} \right) \]

where \( 0 < c \leq 1 \) is a unknown constant that guarantees the equality.

Now take a second-order Taylor expansion of \( L_t \):

\[ \frac{\partial L_t}{\partial Y} \hat{Y}_t + \frac{\partial L_t}{\partial A} \hat{A}_t + \frac{\partial L_t}{\partial \Delta_p \Delta_{p,t}} + \frac{\partial^2 L_t}{\partial^2 \hat{Y}_t \hat{Y}_t} + \frac{\partial^2 L_t}{\partial^2 \hat{A}_t \hat{A}_t} + \frac{\partial^2 L_t}{\partial \hat{Y}_t \partial \hat{A}_t} + \frac{\partial^2 L_t}{\partial \hat{Y}_t \partial \Delta_p \Delta_{p,t}} \]

\[ + \frac{\partial^2 L_t}{\partial \hat{A}_t \partial \Delta_p \Delta_{p,t}} + \frac{\partial^2 L_t}{\partial \hat{A}_t \partial \hat{A}_t} + \frac{\partial^2 L_t}{\partial \hat{A}_t \partial \Delta_p \Delta_{p,t}} + 1 \frac{\partial^2 L_t}{\partial \hat{A}_t \partial \Delta_p \Delta_{p,t}} + 1 \frac{\partial^2 L_t}{\partial \hat{A}_t \partial \Delta_p \Delta_{p,t}} + \Omega \left( \left\| \zeta \right\| \right)^2 \]

\[ \frac{\partial L_t}{

\[ \frac{\partial L_t}{\partial Y} = c \frac{\Delta_p}{A} = c \frac{\Delta_p}{A} \]

since \( \Delta_p = 1 \), which implies that \( L = c \left( Y + n\Phi \right) \).

\(^{20}\)Hölder’s inequality states that \( \int_0^n f(x) g(x) dx \leq \left( \int_0^n f(x)^p dx \right)^{\frac{1}{p}} \left( \int_0^n g(x)^q dx \right)^{\frac{1}{q}} \) when \( \frac{1}{p} + \frac{1}{q} = 1 \). In our case, we have \( f(x) = \left( \frac{P_t(i)}{P_t} \right)^{\frac{q-1}{q}} \frac{Y_t}{nA_t} + \Phi \frac{A_t}{A_t} \), \( g(x) = 1 \), \( p = \frac{q}{q-1} \)

and therefore \( q = \frac{p}{q-1} \).
\[
\frac{\partial L_t}{\partial A} = c \left( -\frac{Y \Delta_p}{A^2} - \frac{n \Phi}{A^2} \right) = -c \left( \frac{Y + n \Phi}{A^2} \right)
\]
\[
\frac{\partial L_t}{\partial \Delta_p} = c Y
\]
\[
\frac{\partial^2 L_t}{\partial \Delta_p^2} = 0
\]
\[
\frac{\partial^2 L_t}{\partial Y \partial A} = -\frac{c}{A^2}
\]
\[
\frac{\partial^2 L_t}{\partial Y^2} = 2c \left( \frac{Y + n \Phi}{A^2} \right)
\]
\[
\frac{\partial^2 L_t}{\partial A^2} = 0
\]
\[
\frac{\partial \Delta_p}{\partial A} = \frac{A}{Y}
\]
\[
\frac{\partial \Delta_p}{\partial Y} = -\frac{c}{A^2}
\]
\[
\frac{\partial \Delta_p}{\partial \Delta_p} = \frac{A}{Y}
\]

Replacing the calculated derivatives in the above expression for \( \dot{L}_t \):

\[
L \left( \dot{L}_t + \frac{1}{2} \dot{L}^2_t \right) = c Y \left( \dot{Y}_t + \frac{1}{2} \dot{Y}^2_t + \Delta_{p,t} - \dot{Y}_t \dot{A}_t \right) - c \left( \frac{Y + n \Phi}{A} \right) \left( \dot{A}_t + \frac{1}{2} \dot{A}^2_t - \dot{A}_t \right) + \frac{c}{A} \dot{A}_t^2 - \frac{c}{A} \dot{Y}_t \dot{A}_t + \mathcal{O} \left( \| \xi \|^3 \right)
\]

\[
L \left( \dot{L}_t + \frac{1}{2} \dot{L}^2_t \right) = c Y \left( \dot{Y}_t + \frac{1}{2} \dot{Y}^2_t + \Delta_{p,t} - \dot{Y}_t \dot{A}_t \right) - c \left( \frac{Y + n \Phi}{A} \right) \left( \dot{A}_t + \frac{1}{2} \dot{A}^2_t - \dot{A}_t \right) + \frac{c}{A} \dot{A}_t^2 - \frac{c}{A} \dot{Y}_t \dot{A}_t + \mathcal{O} \left( \| \xi \|^3 \right)
\]

\[
\dot{L}_t = (1 + n \phi)^{-1} \left[ \dot{Y}_t \left( 1 + \frac{1}{2} \dot{Y}_t - \dot{A}_t \right) + \Delta_{p,t} \right] - \left( \dot{A}_t - \frac{1}{2} \dot{A}^2_t - \dot{A}_t \right) - \frac{1}{2} \dot{L}^2_t + \mathcal{O} \left( \| \xi \|^3 \right)
\]

(65)

This result takes into account that \( \Delta_{p,t} \) is already a term of second-order (recall that \( \phi = \frac{\Phi}{\sqrt{Y}} \)).

The law of motion of \( \Delta_{p,t} \) will be similar to what was determined for \( \Delta_{w,t} \). First, expand \( \Delta_{p,t} \) as a sum (where \( P^*_t \) is the optimal wage at date \( t \))

\[
\Delta_{p,t} = (1 - \xi_p) \left( \frac{P^*_t}{P_t} \right)^{-\theta} + \xi_p (1 - \xi_p) \left( \frac{P^*_t \pi^*_{t-1}}{P_t} \right)^{-\theta}
\]

\[
+ \xi_p^2 (1 - \xi_p) \left( \frac{P^*_{t-2} \pi^*_{t-2} \pi^*_{t-1}}{P_t} \right)^{-\theta} + \xi_p^3 (1 - \xi_p) \left( \frac{P^*_{t-3} \pi^*_{t-3} \pi^*_{t-2} \pi^*_{t-1}}{P_t} \right)^{-\theta}
\]

\[
... \Rightarrow \Delta_{p,t} = (1 - \xi_p) \left( \frac{P^*_t}{P_t} \right)^{-\theta} + \sum_{j=1}^{\infty} \xi_p^j (1 - \xi_p) \left( \frac{P^*_{t-j} \prod_{i=1}^{j} \pi^*_{t-i}}{P_t} \right)^{-\theta}
\]

(66)
One period earlier we have:

$$\Delta_{p,t-1} = (1 - \xi_p) \left( \frac{P_{t-1}^*}{P_{t-1}} \right)^{-\theta} + \sum_{j=1}^{\infty} \xi_p^j (1 - \xi_p) \left( \frac{P_{t-1-j}^* \prod_{i=1}^{j} \pi_{t-i}^{\gamma_p}}{P_{t-1}} \right)^{-\theta}$$

Replacing in equation (67):

$$\xi_p^{\theta} \pi_{t-1}^{-\theta} \Delta_{p,t-1} = \sum_{j=1}^{\infty} \xi_p^j (1 - \xi_p) \left( \frac{P_{t-1-j}^* \prod_{i=1}^{j} \pi_{t-i}^{\gamma_p}}{P_t} \right)^{-\theta}$$

Replacing for the second term in the right-hand side of equation (66):

$$\Delta_{p,t} = (1 - \xi_p) \left( \frac{P_t^*}{P_t} \right)^{-\theta} + \xi_p^{\theta} \pi_{t-1}^{-\theta} \Delta_{p,t-1}$$  \hspace{1cm} (67)

From equation (24) we get:

$$P_t^{1-\theta} = \xi_p \left( \frac{P_{t-1} \pi_{t-1}^{\gamma_p}}{1} \right)^{1-\theta} + (1 - \xi_p) (P_t^*)^{1-\theta} \Leftrightarrow$$

$$1 = \xi_p \left( \frac{P_{t-1} \pi_{t-1}^{\gamma_p}}{1} \right)^{1-\theta} + (1 - \xi_p) \left( \frac{P_t^*}{P_t} \right)^{1-\theta} \Leftrightarrow$$

$$P_t^* = \left( \frac{1 - \xi_p \pi_{t-1}^{\gamma_p}}{1 - \xi_p} \right) \frac{1}{\pi_t}$$

Replacing in equation (67):

$$\Delta_{p,t} = \xi_p^{\theta} \pi_{t-1}^{-\theta} \Delta_{p,t-1} + (1 - \xi_p) \left( \frac{1 - \xi_p \pi_{t-1}^{\gamma_p}}{1 - \xi_p} \right) \frac{1}{\pi_t}$$  \hspace{1cm} (68)

Now take a second-order Taylor approximation of (68):

$$\tilde{\Delta}_{p,t} = \frac{\partial \Delta_{p,t}}{\partial \pi_t} \tilde{\pi}_t + \frac{\partial \Delta_{p,t}}{\partial \pi_{t-1}} \tilde{\pi}_{t-1} + \frac{\partial^2 \Delta_{p,t}}{\partial \pi_t^2} \tilde{\pi}_t^2 + \frac{1}{2} \frac{\partial^2 \Delta_{p,t}}{\partial \pi_t \partial \pi_{t-1}} \tilde{\pi}_t \tilde{\pi}_{t-1} + \frac{1}{2} \frac{\partial^2 \Delta_{p,t}}{\partial \pi_{t-1}^2} \tilde{\pi}_{t-1}^2$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t^2} = \xi_p \frac{\partial}{\partial \pi_t}$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_{t-1}^2} = \xi_p \frac{\partial}{\partial \pi_{t-1}}$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t \partial \pi_{t-1}} = \xi_p \frac{\partial}{\partial \pi_t \partial \pi_{t-1}}$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_{t-1}^2} = 0$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t^2} = 0$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_{t-1}^2} = 0$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t \partial \pi_{t-1}} = 0$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_{t-1}^2} = 0$$

$$\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t^2} = 0$$
\[
\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t \partial \pi_{t-1}} = \frac{\xi_p \theta \gamma_p}{1 - \xi_p}
\]

\[
\frac{\partial^2 \Delta_{p,t}}{\partial \pi_t \partial \Delta_{p|t}} = \xi_p \theta
\]

\[
\frac{\partial^2 \Delta_{p,t}}{\partial \pi_{t-1} \partial \Delta_{p|t}} = -\gamma_p \xi \theta
\]

Then,

\[
\Delta_{p,t} + \frac{1}{2} \Delta_{p,t}^2 = \xi_p \left( \hat{\Delta}_{p,t-1} + \frac{1}{2} \hat{\Delta}_{p,t-1}^2 \right) + \frac{\xi_p \theta}{1 - \xi_p} \left( \hat{\pi}_t + \frac{1}{2} \hat{\pi}_t^2 \right) + \frac{1}{2} \frac{\theta \xi \gamma \gamma_p}{1 - \xi_p} \left( \hat{\pi}_{t-1} + \frac{1}{2} \hat{\pi}_{t-1}^2 \right)^2 - \gamma_p \theta \xi \left( \hat{\pi}_{t-1} + \frac{1}{2} \hat{\pi}_{t-1}^2 \right) \left( \hat{\Delta}_{p,t-1} + \frac{1}{2} \hat{\Delta}_{p,t-1}^2 \right) - \gamma_p \theta \xi \left( \hat{\pi}_{t-1} + \frac{1}{2} \hat{\pi}_{t-1}^2 \right) \left( \hat{\Delta}_{p,t-1} + \frac{1}{2} \hat{\Delta}_{p,t-1}^2 \right) + O \left( \|\zeta\|^3 \right)
\]

\[
\hat{\Delta}_{p,t} = \xi_p \hat{\Delta}_{p,t-1} + \frac{1}{2} \xi_p \theta \left( \hat{\pi}_t^2 + \frac{\gamma_p}{\gamma_p \hat{\pi}_{t-1}^2 - 2 \gamma_p \hat{\pi}_{t-1} \hat{\pi}_{t-1} + O \left( \|\zeta\|^3 \right)
\]

This result takes note of the fact that \( \hat{\Delta}_{p,t} \) is already a term of second-order.

Recall the expression of the disutility from working (61):

\[
V(L_t, \varepsilon_t^b, \varepsilon_t^L) \Delta_{w,t} = \tilde{V} \left( 1 + \hat{\Delta}_{w,t} \right) + \tilde{V}_L \left[ \hat{L}_t + \left( 1 + \sigma_L \right) \hat{L}_t^2 \right] + \hat{L}_t \left( \dot{\varepsilon}_t^b + \dot{\varepsilon}_t^L \right) + O \left( \|\zeta\|^3 \right)
\]

We can rewrite this expression by taking into account that \( \tilde{V} = \tilde{V}_L \frac{1 + \sigma_L}{1 + \sigma_L} \):

\[
V(L_t, \varepsilon_t^b, \varepsilon_t^L) \Delta_{w,t} = \tilde{V}_L \left[ \frac{1 + \hat{\Delta}_{w,t}}{1 + \sigma_L} + \hat{L}_t + \left( 1 + \sigma_L \right) \hat{L}_t^2 / 2 + \hat{L}_t \left( \dot{\varepsilon}_t^b + \dot{\varepsilon}_t^L \right) \right] + O \left( \|\zeta\|^3 \right)
\]

C.3 Welfare expression

Now take the present discounted sum of the welfare equation (60):

\[
\sum_{i=0}^{\infty} \beta^i W_i = \sum_{i=0}^{\infty} \beta^i \left[ U(C_t, H_t, \varepsilon_t^L) - \frac{1}{n} \int_0^u V(L_i (i), \varepsilon_i^b, \varepsilon_i^L) di \right] = \sum_{i=0}^{\infty} \beta^i \left[ \tilde{U} + \tilde{U}_C \left[ \left( \tilde{C}_t - h \tilde{C}_{t-1} \right) + \tilde{C}_t - \tilde{C}_t^2 - \frac{\sigma_e}{2(1-h)} \left( \tilde{C}_t - h \tilde{C}_{t-1} \right)^2 + \varepsilon_t^b \tilde{C}_t^2 - \tilde{C}_t - \tilde{C}_{t-1} \right] - \tilde{V}_L \left( \frac{1 + \hat{\Delta}_{w,t}}{1 + \sigma_L} + \hat{L}_t + \left( 1 + \sigma_L \right) \hat{L}_t^2 / 2 + \hat{L}_t \left( \dot{\varepsilon}_t^b + \dot{\varepsilon}_t^L \right) \right] + O \left( \|\zeta\|^3 \right)
\]

Following Benigno and Woodford (2004), \( \Theta = 1 - \frac{\theta - 1 - \varphi - 1}{\theta - \varphi} < 1 \) measures the inefficiency of the steady-state output level \( \bar{Y} \), so that we can use the steady-state relation \( \tilde{V}_L = (1 - \Theta) \tilde{U}_C \).

Take into account that equations (64) and (68) can be integrated in order to have:
\[
\sum_{t=0}^{\infty} \beta^t \Delta_{w,t} = \frac{1}{2} \varphi (1 + \sigma_L) (\varphi \sigma_L + 1) + \frac{\xi_w}{(1 - \xi_w)(1 - \beta \xi_w)} \sum_{t=0}^{\infty} \beta^t (\bar{v}_{w,t}^2 + \gamma_w \bar{v}_{t-1}^2 - 2\gamma_w \bar{v}_{w,t} \bar{v}_{t-1}) + O \left( ||\zeta||^3 \right)
\]

\[
\sum_{t=0}^{\infty} \beta^t \Delta_{p,t} = \frac{1}{2} \frac{\xi_p \theta}{(1 - \xi_p)(1 - \beta \xi_p)} \sum_{t=0}^{\infty} \beta^t (\bar{v}_{p,t}^2 + \gamma_p \bar{v}_{t-1}^2 - 2\gamma_p \bar{v}_{p,t} \bar{v}_{t-1}) + O \left( ||\zeta||^3 \right)
\]

Replacing this in the welfare expression and remembering the expression for labour (65), we get, after some algebra:

\[
\sum_{t=0}^{\infty} \beta^t W_t = \sum_{t=0}^{\infty} \beta^t \left[ \bar{U} + \bar{U}_C C \right] - \frac{\xi_w \varphi (\varphi \sigma_L + 1)(1 - \Theta)}{2 (1 - \xi_w)(1 - \beta \xi_w)} \cdot \frac{\xi_p \theta (1 - \Theta)}{2 (1 - \xi_p)(1 - \beta \xi_p)} \cdot \frac{(1 - n \phi)}{(1 + n \phi)^2} > 0
\]

\[
u_2 = \frac{2 (1 - \xi_p)(1 - \beta \xi_p)(1 + n \phi)}{(1 - \Theta)(1 + n \phi - \sigma_L)} > 0 \quad \text{if } 1 + n \phi > \sigma_L
\]

\[
u_4 = \frac{1 - \Theta}{1 + n \phi} > 0 \quad 21
\]

The welfare expression at moment \( t \) used in section 4.2.3 is the following:

\[
W_t = \bar{U} + \bar{U}_C C \left[ \left( \bar{C}_t - h \bar{C}_{t-1} \right) + \frac{1}{2} \left( \bar{C}_t^2 - h^2 \bar{C}_{t-1}^2 \right) - \frac{\sigma_c}{2 (1 - h)} \left( \bar{C}_t - h \bar{C}_{t-1} \right)^2 + \frac{1 - h}{2 (1 - \sigma_c)} \bar{v}_t^2 + \frac{1}{2} \bar{v}_t \left( \bar{C}_t - h \bar{C}_{t-1} \right) - u_1 (\bar{v}_{w,t}^2 + \gamma_w \bar{v}_{t-1}^2 - 2\gamma_w \bar{v}_{w,t} \bar{v}_{t-1}) - u_2 (\bar{v}_{p,t}^2 + \gamma_p \bar{v}_{t-1}^2 - 2\gamma_p \bar{v}_{p,t} \bar{v}_{t-1}) - u_3 \bar{y}_t^2 + u_4 \bar{y}_t \bar{A}_t - u_5 \bar{y}_t \left( 1 + \bar{v}_t \right) \right]
\]

\[21\] Obviously, for the foreign economy we need to replace \( n \) for \( (1 - n) \).


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<th>Date</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/07</td>
<td>THE FORWARD PREMIUM OF EURO INTEREST RATES</td>
<td>Sónia Costa, Ana Beatriz Galvão</td>
</tr>
<tr>
<td>3/07</td>
<td>ADJUSTING TO THE EURO</td>
<td>Gabriel Fagan, Vítor Gaspar</td>
</tr>
<tr>
<td>4/07</td>
<td>SPATIAL AND TEMPORAL AGGREGATION IN THE ESTIMATION OF LABOR DEMAND FUNCTIONS</td>
<td>José Varejão, Pedro Portugal</td>
</tr>
<tr>
<td>5/07</td>
<td>PRICE SETTING IN THE EURO AREA: SOME STYLISED FACTS FROM INDIVIDUAL PRODUCER PRICE DATA</td>
<td>Philip Vermeulen, Daniel Dias, Maarten Dossche, Erwan Gautier, Ignacio Hernando, Roberto Sabbatini, Harald Stahl</td>
</tr>
<tr>
<td>6/07</td>
<td>A STOCHASTIC FRONTIER ANALYSIS OF SECONDARY EDUCATION OUTPUT IN PORTUGAL</td>
<td>Manuel Coutinho Pereira, Sara Moreira</td>
</tr>
<tr>
<td>7/07</td>
<td>CREDIT RISK DRIVERS: EVALUATING THE CONTRIBUTION OF FIRM LEVEL INFORMATION AND OF MACROECONOMIC DYNAMICS</td>
<td>Diana Bonfim</td>
</tr>
<tr>
<td>8/07</td>
<td>CHARACTERISTICS OF THE PORTUGUESE ECONOMIC GROWTH: WHAT HAS BEEN MISSING?</td>
<td>João Amador, Carlos Coimbra</td>
</tr>
<tr>
<td>9/07</td>
<td>TOTAL FACTOR PRODUCTIVITY GROWTH IN THE G7 COUNTRIES: DIFFERENT OR ALIKE?</td>
<td>João Amador, Carlos Coimbra</td>
</tr>
<tr>
<td>10/07</td>
<td>IDENTIFYING UNEMPLOYMENT INSURANCE INCOME EFFECTS WITH A QUASI-NATURAL EXPERIMENT</td>
<td>Mário Centeno, Alvaro A. Novo</td>
</tr>
<tr>
<td>11/07</td>
<td>HOW DO DIFFERENT ENTITLEMENTS TO UNEMPLOYMENT BENEFITS AFFECT THE TRANSITIONS FROM UNEMPLOYMENT INTO EMPLOYMENT</td>
<td>John T. Addison, Pedro Portugal</td>
</tr>
<tr>
<td>12/07</td>
<td>INTERPRETATION OF THE EFFECTS OF FILTERING INTEGRATED TIME SERIES</td>
<td>João Valle e Azevedo</td>
</tr>
<tr>
<td>13/07</td>
<td>EXACT LIMIT OF THE EXPECTED PERIODOGRAM IN THE UNIT-ROOT CASE</td>
<td>João Valle e Azevedo</td>
</tr>
<tr>
<td>14/07</td>
<td>INTERNATIONAL TRADE PATTERNS OVER THE LAST FOUR DECADES: HOW DOES PORTUGAL COMPARE WITH OTHER COHESION COUNTRIES?</td>
<td>João Amador, Sónia Cabral, José Ramos Maria</td>
</tr>
<tr>
<td>15/07</td>
<td>INFLATION (MIS)PERCEPTIONS IN THE EURO AREA</td>
<td>Francisco Dias, Cláudia Duarte, António Rua</td>
</tr>
<tr>
<td>16/07</td>
<td>LABOR ADJUSTMENT COSTS IN A PANEL OF ESTABLISHMENTS: A STRUCTURAL APPROACH</td>
<td>João Miguel Ejarque, Pedro Portugal</td>
</tr>
<tr>
<td>17/07</td>
<td>A MULTIVARIATE BAND-PASS FILTER</td>
<td>João Valle e Azevedo</td>
</tr>
<tr>
<td>18/07</td>
<td>AN OPEN ECONOMY MODEL OF THE EURO AREA AND THE US</td>
<td>Nuno Alves, Sandra Gomes, João Sousa</td>
</tr>
<tr>
<td>19/07</td>
<td>IS TIME RIPE FOR PRICE LEVEL PATH STABILITY?</td>
<td>Vitor Gaspar, Frank Smets, David Vestin</td>
</tr>
<tr>
<td>Date</td>
<td>Title</td>
<td>Authors</td>
</tr>
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<td>------</td>
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<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>20/07</td>
<td>IS THE EURO AREA M3 ABANDONING US?</td>
<td>Nuno Alves, Carlos Robalo Marques, João Sousa</td>
</tr>
<tr>
<td>21/07</td>
<td>DO LABOR MARKET POLICIES AFFECT EMPLOYMENT COMPOSITION? LESSONS FROM EUROPEAN COUNTRIES</td>
<td>António Antunes, Mário Centeno</td>
</tr>
<tr>
<td>2008</td>
<td>THE DETERMINANTS OF PORTUGUESE BANKS’ CAPITAL BUFFERS</td>
<td>Miguel Boucinha</td>
</tr>
<tr>
<td>1/08</td>
<td>DO RESERVATION WAGES REALLY DECLINE? SOME INTERNATIONAL EVIDENCE ON THE DETERMINANTS OF RESERVATION WAGES</td>
<td>John T. Addison, Mário Centeno, Pedro Portugal</td>
</tr>
<tr>
<td>3/08</td>
<td>UNEMPLOYMENT BENEFITS AND RESERVATION WAGES: KEY ELASTICITIES FROM A STRIPPED-DOWN JOB SEARCH APPROACH</td>
<td>John T. Addison, Mário Centeno, Pedro Portugal</td>
</tr>
<tr>
<td>4/08</td>
<td>THE EFFECTS OF LOW-COST COUNTRIES ON PORTUGUESE MANUFACTURING IMPORT PRICES</td>
<td>Fátima Cardoso, Paulo Soares Esteves</td>
</tr>
<tr>
<td>5/08</td>
<td>WHAT IS BEHIND THE RECENT EVOLUTION OF PORTUGUESE TERMS OF TRADE?</td>
<td>Fátima Cardoso, Paulo Soares Esteves</td>
</tr>
<tr>
<td>6/08</td>
<td>EVALUATING JOB SEARCH PROGRAMS FOR OLD AND YOUNG INDIVIDUALS: HETEROGENEOUS IMPACT ON UNEMPLOYMENT DURATION</td>
<td>Luis Centeno, Mário Centeno, Álvaro A. Novo</td>
</tr>
<tr>
<td>7/08</td>
<td>FORECASTING USING TARGETED DIFFUSION INDEXES</td>
<td>Francisco Dias, Maximiano Pinheiro, António Rua</td>
</tr>
<tr>
<td>8/08</td>
<td>STATISTICAL ARBITRAGE WITH DEFAULT AND COLLATERAL</td>
<td>José Fajardo, Ana Lacerda</td>
</tr>
<tr>
<td>9/08</td>
<td>DETERMINING THE NUMBER OF FACTORS IN APPROXIMATE FACTOR MODELS WITH GLOBAL AND GROUP-SPECIFIC FACTORS</td>
<td>Francisco Dias, Maximiano Pinheiro, António Rua</td>
</tr>
<tr>
<td>10/08</td>
<td>VERTICAL SPECIALIZATION ACROSS THE WORLD: A RELATIVE MEASURE</td>
<td>João Amador, Sónia Cabral</td>
</tr>
<tr>
<td>11/08</td>
<td>INTERNATIONAL Fragmentation of production in the Portuguese economy: what do different measures tell us?</td>
<td>João Amador, Sónia Cabral</td>
</tr>
<tr>
<td>12/08</td>
<td>IMPACT OF THE RECENT REFORM OF THE PORTUGUESE public employees’ pension system</td>
<td>Maria Manuel Campos, Manuel Coutinho Pereira</td>
</tr>
<tr>
<td>13/08</td>
<td>EMPIRICAL EVIDENCE ON THE BEHAVIOR AND STABILIZING ROLE OF FISCAL AND MONETARY POLICIES IN THE US</td>
<td>Manuel Coutinho Pereira</td>
</tr>
<tr>
<td>14/08</td>
<td>IMPACT ON WELFARE OF COUNTRY HETEROGENEITY IN A CURRENCY UNION</td>
<td>Carla Soares</td>
</tr>
</tbody>
</table>