Optimal Inflation Weights in the Euro Area*

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This study investigates the appropriate measure for stabilizing inflation in the euro area. We use a model that accounts for both the heterogeneity observed in the degree of price rigidities across regions and sectors, and asymmetry of real disturbances in relative prices. Our work shows that the optimal weights to assign to each region or sector result from complex interactions between the degree of price stickiness, economic size, and the distribution of shocks within regions.

JEL Codes: E52, F41.

1. Introduction

The importance given to stabilizing inflation is not only in line with the European Central Bank's (ECB's) primary objective as imposed by the Maastricht Treaty but also with opinion in the academic literature, where complete price stability within the class of sticky-price models constitutes a robust optimal monetary policy.[1] However, heterogeneity in the degree of price stickiness across regions and sectors, and asymmetry in the shocks, is characteristic of the

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[1]See Woodford (2003) and references therein.

euro area. Therefore the practical implementation of targeted inflation policy crucially depends on which measure of inflation the ECB needs to establish to offset the distortions caused by price volatility. This paper investigates optimal inflation targeting for the euro area using a multi-region and multi-sector model with asymmetric demand shocks.

At present, the ECB stabilizes the Monetary Union Index of Consumer Prices (MUICP), which is a sum of the single region's HICP indexes, weighted by the economic size of each region. This practice is in stark contrast with recent academic results that conclude that in a two-region model, optimal monetary policy must target inflation in the region with the highest degree of nominal rigidities instead of using an aggregate measure of inflation across regions.[2] This naturally raises the question of whether monetary policy should take into account the dispersion of inflation across regions and sectors in the euro area, which is characterized by different degrees of nominal price rigidities and asymmetric shocks across regions and sectors.

The idea of stabilizing a core price index is in the Keynesian tradition of focusing on a core rather than an overall cost-of-living index. This is also in line with the monetarist recommendation to stabilize a long-run index and ignore relative price movement such as oil price shocks (Goodfriend and King 1997). In the empirical literature, Bryan and Cecchetti (1994) and Cogley (2002) identify core inflation as a more persistent component of inflation and consider it, from a policy point of view, to be a more important indicator than broader inflation measurement, since fluctuations in food and energy prices are regarded as transitory components of overall movements in inflation.

Aoki (2001) and Benigno (2004) use a theoretical model to formalize these main empirical results. Aoki (2001) develops a two-sector dynamic general equilibrium model with a flexible-price sector along with a sticky-price sector and shows that the optimal monetary policy (characterized as an inflation-targeting regime) stabilizes core inflation rather than a broader measure of inflation. Benigno (2004) focuses on the optimal policy in a currency area and develops a two-region model. Benigno's main conclusion is that the optimal

[2] See Benigno (2004). A similar result holds in a two-sector model, as shown in Aoki (2001). We discuss these studies in the rest of the introduction.

plan can be approximated by what he calls a second-best solution. This allows for a context of asymmetric shocks and a different level of price rigidities between regions, and minimizes a welfare criterion that accounts for the exact magnitude of all the distortions in the economy. This is an inflation-targeting policy in which greater weight is given to inflation in those regions characterized by a higher degree of nominal rigidity.

Our paper extends this line of research. We use the microeconomic evidence on the frequency of price adjustments in the euro area to verify whether the "stickiness principle" underlined by the baseline models (Aoki 2001 and Benigno 2004) still holds in a more realistic multi-region setting. Moreover, given that differences in the frequency of price adjustment are significant not only across regions but also across sectors, we also investigate the difference between sectoral inflation targeting and regional inflation targeting. This aspect is of crucial importance for the ECB, which faces the challenge of aggregating euro-area inflation across sectors and regions.

We develop a multi-region/multi-sector model by focusing on ten regions and ten sectors, and go on to derive a microfounded welfare function. We then use this criterion to determine the unconditional optimal monetary policy as described in Woodford (2003), and we compare it with two alternative policy regimes: first, a pure inflation-targeting regime, in which aggregate inflation is based on weighting inflation for each region/sector according to its economic size, and second, an optimal inflation-targeting regime, in which the weights for each region's/sector's inflation are chosen optimally. We calculate the welfare deadweight loss of these two alternative regimes against the optimal policy that minimizes the microfounded welfare function.

The analysis establishes the following results. First, a pure inflation-targeting regime, in which aggregate inflation is based on inflation weighting for each region/sector according to its economy size, is always sub-optimal. The only exception is the case in which all regions/sectors have the same price stickiness. In all the other cases there is an optimal set of weights that do not coincide with the relative size of the regions/sectors. In addition, the optimal inflation target turns out to be a close proxy of optimal monetary policy since the welfare loss implied by these two monetary regimes is very similar.

Differing from a two-region model, the presence of multiple regions and asymmetric demand shocks that impact the natural level of relative prices produces optimal weights from complex interactions between the degree of price stickiness, economic size, and the distribution of the shocks within regions. In this case the "stickiness principle" is less evident. Our results show that implementing the optimal inflation target is a difficult task for the ECB, and there is not a simple rule-of-thumb rule that can be used to choose weights optimally.

Numerous related studies investigate optimal monetary policy under a variety of imperfections. Erceg, Henderson, and Levin (2000) consider the case of distortions in goods and labor markets, Huang and Liu (2005) study the effect of nominal rigidities in the production of intermediate goods, and Bodenstein, Erceg, and Guerrieri (2008) focus on optimal policy when shocks originate in an energy sector. The common policy prescription across these studies is that inflation stabilization should attach more weights to the sectors in which nominal rigidities are more pronounced, as they create larger real distortions. More recently, some studies have extended the design of monetary policy for a currency area in different directions, making such "stickiness principles" less clear cut. Lombardo (2006) considers a second source of heterogeneity across regions (i.e., a different degree of competition) together with the different degrees of nominal rigidity and shows that the weights attached to the region-specific inflation rates should increase with the degree of competition, implying an ambiguous outcome on the inflation weights if the model requires a positive correlation between price flexibility and degree of competition.

Benigno and Lopez-Salido (2006) deepen Benigno's (2004) framework by assuming that a fraction of firms set prices in a backward-looking fashion. They find that the optimal inflation-targeting policy model, which reweights countries according to degrees of rigidity and their component of backward-looking firms and their output-gap stabilization policy, performs better than the HICP inflation targeting only for some calibrations of the model in terms of welfare, thus suggesting that it may not be desirable for the ECB to abandon HICP targeting. Finally, Eusepi, Hobijn, and Tambalotti (2011) develop a multi-sector New Keynesian model, calibrated to match U.S. data on price stickiness, labor shares, and inflation across sectors, to show that optimal inflation targeting can be closely approximated by a core inflation target which does not include the more volatile components of the PCE-based price index.

The remainder of the paper is structured as follows. Section 2 provides evidence on heterogeneity in the euro-area across regions and sectors. Section 3 lays out the theoretical model. Section 4 derives the welfare function and outlines the optimal monetary policy and inflation-targeting plans. Section 5 describes the calibration of the model. Section 6 reports the results of the simulations. Section 7 contains the conclusions.

2. Heterogeneity in Euro-Area Regions and Sectors

In this section, we compare the size and frequency of price adjustment for regions and sectors within the euro area, using the micro evidence of price setting for euro-area countries in Dhyne et al. (2006). We focus on ten regions within this area and on ten macro sectors. The number of regions and sectors considered is primarily related to data availability on the frequency of price changes. We will use this information to calibrate the theoretical model described in the next section.

Consumer price inflation in the euro area is measured by the Harmonised Index of Consumer Prices (HICP), compiled by Eurostat and the national statistical institutes using harmonized statistical methods. Each member state measures the month-to-month movements in sector prices as an average of price indexes, using expenditure weights (n_s), which are an appropriate reflection of consumption patterns. The HICP is classified according to the four-digit categories and subcategories of the Classification of Individual Consumption by Purpose (COICOP). HICPs provide the basis for compiling the Monetary Union Index of Consumer Prices (MUICP), which provides the official measure of inflation in the euro area. The MUICP is calculated as a weighted average of the HICPs of the participating regions of the EMU, where the weights (n_r) are represented by the economic size of each region.[3]

[3] Up to 2000 the weight of a member state is calculated as the share of private domestic consumption expenditure in the EMU; from 2001 the region weight of a member state is calculated as the share of household final monetary consumption expenditure of the euro area.

The ECB remit is to maintain annual MUICP inflation rates below, but close to, 2 percent over the medium term. According to the theoretical academic results highlighted in the introduction, the ECB's choice to target aggregate inflation should consider not only the economic size of regions/sectors but also the distribution of price stickiness. The second column in table 1 reports the economic size of each region (top panel) and the economic size of each sector (bottom panel) in the economy, calculated according to consumer expenditure in each region or sector. Most of the larger regions measured in terms of consumption expenditure (e.g., Germany, Italy, and Spain), with the exception of France, show a higher degree of price stickiness. Looking at sectors, restaurants and hotels (which account for about 30 percent of total expenditure) show the lowest frequency of price adjustment, while the energy sector is the most flexible sector in terms of price changes. The importance of the frequency of price adjustment is evaluated in the fourth column by the duration of price contracts, which can be approximated by the reciprocity of price-change frequency.[4]

The frequency of price changes, calculated within the Eurosystem Inflation Persistence Network as an average over the period 1996–2001, represents the average share of prices that are revised in a given month (see Dhyne et al. 2006 for its calculation). The monthly frequency of price changes for the euro area is equal on average to 15 percent, while this works out to 24.8 percent for the United States, according to Bils and Klenow's (2004) calculations on a subsample of fifty products. According to Dhyne et al. (2006), the source of cross-region variation is likely to be both structural (consumption structure, outlet composition) and methodological (the treatment of sales and quality adjustment by each national statistical institute), or reflects differences in the relative importance of regulated prices across regions. Nevertheless, table 1 shows that there is a high degree of heterogeneity in price adjustments across both regions and sectors in the euro area, which may represent an effective challenge for the conduct of monetary policy.

[4]The duration of price contracts should be read with caution, given that according to Dhyne et al. (2006) the inverse frequency calculated as a proxy of average duration turns out to be systematically much lower than the average duration.

Table 1. Economic Size and Frequency of Price Adjustment in Europe

	Economic Size (n_r)	Frequency of Price Adjustment	Average Duration in Quarters
Italy	19.9	10.0	3.3
Spain	12.5	13.3	2.5
Germany	30.0	13.5	2.5
Austria	3.3	15.4	2.1
Netherlands	5.4	16.2	1.9
Belgium	3.5	17.6	1.6
Finland	1.6	20.3	1.6
France	21.2	20.9	1.6
Portugal	2.3	21.1	1.6
Luxembourg	0.3	23.0	1.4
Euro Area		15.1	2.2
United States		24.8	1.3
	Economic Size (n_s)	**Frequency of Price Adjustment**	**Average Duration in Quarters**
Restaurants and Hotels	30.3	4.2	7.9
Housing	2.7	6.5	5.1
Recreation and Culture	6.5	6.6	5.1
Furnishing and Household Equipment	5.0	7.2	4.6
Transport and Communications	8.5	7.2	4.6
Miscellaneous Goods and Services	4.8	7.3	4.5
Clothing	16.2	8.4	4.0
Processed Food	7.4	12.5	2.7
Unprocessed Food	7.8	37.2	0.9
Energy	10.8	78.8	0.4

Source: Dhyne et al. (2006) for euro-area data; Bils and Klenow (2004) for the United States.
Notes: n_r: region share of household monetary consumption expenditure. n_s: expenditure weights which reflect the consumption patterns of households. Frequency of Price Adjustment: represents the average share of prices revised in a given month. Average Duration in Quarters: inverse of the frequency of price adjustment.

3. The Model

We develop a multi-region model similar to Aoki (2001) and Benigno (2004) to accommodate the microeconomic evidence on price stickiness across regions and sectors described in the previous section. This addresses the question of what is the optimal inflation-targeting policy in a currency area such as the euro area.[5] Ideally one would have to consider regions and sectors in a joint model with two degrees of heterogeneity within regions and between regions. In this paper, we are going to consider this model but with two different calibrations, focusing respectively on different frequencies of price adjustment across both regions and sectors.[6]

The economy is made up of a continuum of agents defined over the unit interval $[0, 1]$. Each agent manufactures a single differentiated product, u, and consumes a fraction of all the goods produced in the economy. In each region, a measure n_i of goods is produced, with $i = 1, 2, \ldots, K$, and the total sum of produced goods is normalized equal to 1, such that $\sum_{i=1}^{K} n_i = 1$. All produced goods are traded across regions, and there is no migration across regions. Goods are differentiated and prices are set on a staggered basis. In the economy there is a single central bank and K fiscal authorities, each of which has sovereignty over one region only.

The demand side of the model comprises a household's j preferences defined by

$$U_t^j = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[U(C_s^j) + L\left(\frac{M_s^j}{P_s}, \xi^i\right) - V(y_s^j, z_s^j) \right],$$

where the upper index j denotes a variable that pertains to agent j, while the upper index i denotes a variable specific to region i. The term E_t denotes the expectation conditional on the information set at date t, and the parameter β is the intertemporal discount factor $0 \leq \beta \leq 1$. During each period s, each agent j gains utility from a consumer basket, C_s^j, of goods produced in region i, defined as

[5]The theoretical framework is also close and extends the works by Galí and Monacelli (2005) and Soffritti and Zanetti (2008).

[6]We thank an anonymous referee for this suggestion.

$$C_i^j \equiv \left[\left(\frac{1}{n^i} \right)^{\frac{1}{\sigma}} \int_{u \in i} c^j(u)^{\frac{\sigma-1}{\sigma}} du \right]^{\frac{\sigma}{\sigma-1}},$$

and this applies to the liquidity services of holding money (M_s^j/P_s), while he/she receives disutility from producing goods, $V(y_s^j, z_s^j)$.

The terms ξ^i and z_s^j denote exogenous shocks to (region-specific) money holdings and (agent-specific) disutility from production, respectively. The consumption index, C^j, is defined as $C^j \equiv \left[\prod_{i=1}^K (C_i^j)^{n_i}\right]\left[\prod_{i=1}^K n_i\right]^{-1}$, for $i = 1, 2, \ldots, K$. The parameter $\sigma > 1$ is the elasticity of substitution across goods produced within a region,[7] whereas the elasticity of substitution between the bundles C_i is set equal to 1. The total demand for each good u produced in region i is

$$y_i^d(u) = \left(\frac{p(u)}{P_i} \right)^{-\sigma} \left(\frac{C^W}{P_i^R} + G_i \right),$$

where $p(u)$ is the price of the product u; C^W is union aggregate consumption (defined as $C^W \equiv \int_0^1 C^j dj$); P_i^R is the relative price in region i, defined as $P_i^R \equiv P_i/P$, where $P_i = \int_0^1 p(u)du$ and $P = \left[\prod_{i=1}^K (P_i)^{n_i}\right]\left[\prod_{i=1}^K n_i\right]^{-1}$; and G_i is public expenditure in region i.

Aggregate demand is represented by standard Euler equations derived by maximizing the utility function subject to budget constraints for each household j in each region i.

The supply side of the model comprises imperfectly competitive firms that set prices as in Calvo (1983). In each period, a seller faces a fixed probability $1-\alpha$ of adjusting its price, and receives a subsidy τ^i that offsets the distortions generated by monopolistic competition in the steady state. Producers in the same region set similar prices since they face the same discounted future demands and future marginal costs under the hypothesis that the new price is maintained. The optimal price, $\tilde{p}_t(u)$, is given by

[7] In this model σ is common to all regions. For a heterogeneous degree of competition, see Lombardo (2006).

$$\tilde{p}_t(u) = \frac{\sigma}{(\sigma-1)(1-\tau^i)} \frac{E_t \sum_{k=0}^{\infty} (\alpha^i \beta)^k V_y(\tilde{y}^d_{t,t+k}(u), z^i_{t+k}) \tilde{y}^d_{t,t+k}(u)}{E_t \sum_{k=0}^{\infty} (\alpha^i \beta)^k \lambda_{t+k} \tilde{y}^d_{t,t+k}(u)}, \tag{1}$$

where $\tilde{y}^d_{t,t+k}(u)$ is the total demand for good u at time $t+k$, $\lambda_{t+k} = U_C(C_{t+k})/P_{t+k}$ with $U_C(C_{t+k})$ denoting the marginal utility of consumption, and $V_y(\tilde{y}^d_{t,t+k}(u), z^i_{t+k})$ is the derivative of the disutility function $V(\cdot)$ with respect to total demand. The state equation for aggregate prices in each region is

$$P^{1-\sigma}_{i,t} = \alpha^i P^{1-\sigma}_{i,t-1} + (1-\alpha^i)\tilde{p}_t(u)^{1-\sigma}, \tag{2}$$

for $i = 1, 2, \ldots, K$. Aggregate supply is represented by standard New Keynesian Phillips curves derived by combining equations (1) and (2) for each region i.

The model is closed by requiring that the government of each region i maintain a balanced budget, and assuming that the instrument of monetary policy is set in terms of the one-period risk-free interest rate on the nominal bonds denominated in the common currency.

3.1 Equilibrium under Flexible and Sticky Prices

We first focus on fluctuations around the steady state in the flexible-price model since it is the relevant equilibrium for welfare evaluation. We then describe the model with sticky prices.

Before proceeding with the analysis, some of the notation we use should be clarified. We denote the log-deviation of X_t from its steady state in the flexible-price model with $\tilde{X}_t$, while $\hat{X}_t$ denotes the deviation of the same variable in the sticky-price model. A world variable X^W is defined as $X^W \equiv \sum_{i=1}^{K} n_i X_i$. In addition, X^R_i denotes a relative variable with respect to the world, defined as $X^R_i \equiv X_i - X^W$.

The solution of the model with flexible prices is described by the equations

$$\tilde{C}^W_t = \frac{\eta}{\rho+\eta}(\bar{Y}^W_t - g^W_t), \tag{3}$$

$$\tilde{Y}^W_t = \frac{\eta}{\rho+\eta}\bar{Y}^W_t + \frac{\rho}{\rho+\eta} g^W_t, \tag{4}$$

$$\tilde{P}^R_{i,t} = \frac{\eta}{1+\eta}(g^R_{i,t} - \bar{Y}^R_{i,t}), \tag{5}$$

where $\bar{Y}^R_{i,t}$ ($\bar{Y}^W_t$) and $g^R_{i,t}$ (g^W_t) are region-specific (world) shocks to supply and government purchase, respectively, and η and ρ are, respectively, the inverse elasticity of goods production and the intertemporal elasticity of consumption substitution. The natural interest rate, $\tilde{R}_t$, in equilibrium, under zero inflation rate, is

$$\tilde{R}_t = \frac{\rho\eta}{\rho+\eta} E_t[(\bar{Y}^W_{t+1} - \bar{Y}^W_t) - (g^W_{t+1} - g^W_t)]. \tag{6}$$

The solution of the model with sticky prices is described by the standard Euler and aggregate output equations:

$$E_t\hat{C}^W_{t+1} = \hat{C}^W_t + \rho^{-1}(\hat{R}_t - E_t\pi^W_{t+1}), \tag{7}$$

$$\hat{Y}_{i,t} = -\hat{P}^R_{i,t} + \hat{C}^W_t + g^i_t, \tag{8}$$

defined for each region $i = 1, 2, \ldots, K$. Similarly, the aggregate supply equation for each region $i = 1, 2, \ldots, K$, is equal to

$$\pi^i_t = \beta E_t\pi^i_{t+1} - k^i_P(\hat{P}^R_{i,t} - \tilde{P}^R_{i,t}) + k^i_C(\hat{C}^W_t - \tilde{C}^W_t), \tag{9}$$

which shows that region-specific inflation rates depend on the expectations of future price-setting behavior[8] as well as on the deviations of both the union output gap from zero and relative prices from their natural rates.[9] In addition, the definition of relative price for each region $i = 1, 2, \ldots, K$ implies

$$\hat{P}^R_{i,t} = \hat{P}^R_{i,t-1} + \pi^i_t - \pi^W_t. \tag{10}$$

The equilibrium dynamics of the variables $\{\tilde{C}^W_t, \tilde{Y}^W_t, \tilde{P}^R_{i,t}, \tilde{R}_t, \hat{C}^W_t, \hat{Y}_{i,t}, \hat{P}^R_{i,t}, \hat{P}^R_{i,t}, \pi^i_t, \pi^W_t, \hat{R}_t\}$ is described by equations (3)–(10) together with the equation for the monetary policy rule and the definitions of world variables $\hat{C}^W_t$ and π^W_t.

[8]Benigno and Lopez-Salido (2006) allow for a hybrid model in which past inflation plays a role in the inflation dynamics that we do not consider.

[9]Note that $k^i_C \equiv [(1-\alpha^i\beta)(1-\alpha^i)/\alpha^i][(\rho+\eta)/(1+\rho\eta)]$ and $k^i_P = k^i_C[(1+\eta)/(\rho+\eta)]$.

3.2 Shocks Structure

Following Benigno (2004), we impose an asymmetric demand shock. We implement this shock by assuming that the natural level of relative prices $\tilde{P}^R_{i,t}$ moves proportionally to the exogenous process ζ_t defined as follows:

$$\tilde{P}^R_{i,t} = p_i \zeta_t$$

with

$$\zeta_t = \phi \zeta_{t-1} + \varepsilon_t,$$

where ε_t is a white-noise shock with zero mean and variance equal to σ^2_ϵ. We assume that all regions show the same persistence of the shock affecting the flexible relative prices whose variance is $\sigma^2_{\tilde{P}^R_{i,t}} = p_i^2 \sigma^2_\epsilon$.

In order for the shock structure to be consistent, given that the shocks refer to relative prices, we need to impose the following constraint:

$$\sum_{i=1}^{K} n_i p_i = 0. \tag{11}$$

Equation (11) describes how the shock is distributed across regions. In a two-region model only the shock to one region needs to be imposed for the shock to the other region to be automatically calculated. In a multi-region case we can assume different distributions of the shock across regions that are consistent with equation (11).

In section 6 we investigate how both optimal inflation weights and welfare losses are affected by such alternative distributions.

4. Welfare Comparison

The main goal of the ECB is to stabilize the Monetary Union Index of Consumer Prices (MUICP), which is a weighted average of the single region's HICP index, where the weights are the economic size of each region. However, Benigno (2004) shows that in a two-region model with asymmetries in price rigidity, the optimal policy involves giving higher weights to the inflation in regions with a higher degree of nominal rigidity. In order to investigate to what extent the two-region results hold in a multi-region setting, we derive the optimal monetary policy and then evaluate it against two alternative policy regimes: (i) a pure inflation-targeting regime, in which aggregate inflation weights the inflation of each region according to its economy size, and (ii) an optimal inflation-targeting regime, in which the weights to each region's inflation are chosen optimally.

The optimal monetary policy is obtained as the minimization of a deadweight loss from the discounted sum of a weighted average of the average utility flows of all households across all regions K, assuming that the liquidity services provided from holding real money balances are small. The welfare criterion is therefore defined as

$$\mathbf{W}_t = E_0 \sum_{j=0}^{\infty} \sum_{i=1}^{K} \beta^j n_i \left[U(C_{t+j}^j) - \int_0^1 V(y_{t+j^j}, z_{t+j}^j) dj \right]. \quad (12)$$

To evaluate welfare we use a second-order Taylor expansion of $\mathbf{W}_t$ around the steady state, as in Woodford (2003) and Benigno (2004), which leads us to rewrite equation (12) as $\mathbf{W}_t = -\Omega E_t \sum_{j=0}^{\infty} \beta^j L_{t+j}$, with

$$L_{t+j} = \Lambda[c_{t+j}^W - \bar{c}^W]^2 + \Gamma \left[\sum_{i=1}^{K} n_i (\hat{P}_{i,t}^R - \tilde{P}_{i,t}^R)^2 \right] + \sum_{i=1}^{K} \varsigma_i (\pi_{t+j}^i)^2$$
$$+ t.i.p. + o(\|\xi\|^3), \quad (13)$$

where $t.i.p.$ denotes parameters independent from policy, $o(\|\xi\|^3)$ includes terms of third or higher order, and the coefficients Ω, Λ, Γ, ς_i, and d^i are defined as

$$\Omega \equiv \frac{1}{2} U_C \bar{C} \left(\sum_{i=1}^{K} n_i d^i \right) \sigma (1 + \sigma\eta),$$

$$\Lambda \equiv \frac{1}{\sigma} \left(\sum_{i=1}^{K} n_i (k_C^i)^{-1} \right)^{-1},$$

$$\Gamma \equiv \frac{1}{\sigma} \left(\sum_{i=1}^{K} n_i (k_P^i)^{-1} \right)^{-1},$$

$$\varsigma_i \equiv \frac{n_i d^i}{\left(\sum_{i=1}^{K} n_i d^i\right)},$$

$$d^i \equiv \frac{\alpha^i}{(1-\alpha^i)(1-\alpha^i\beta)}.$$

The loss function (13) shows that a currency union has three sources of inefficiency: first, an inefficient output level; second, inefficient price dispersion; and third, inefficient response of relative prices to asymmetric shocks due to price stickiness. Equation (13) shows that the first-best option is one in which the central bank offsets the three inefficiencies. However, this outcome is not feasible if the degree of price stickiness differs across regions because of the mismatch between objectives and instruments.

As described in the next section, we use $\mathbf{W}_t$ to derive the optimal monetary policy. However, we use the unconditional expectation of the welfare function (as in Woodford 1999), to compare the welfare loss in alternative monetary policies:

$$\begin{aligned} W &= 100 \cdot \Omega \cdot E(E_0 \mathbf{W}_{t+j}) \\ W &= -100 \cdot \Omega \\ &\quad \cdot \left[\Lambda var\left(\hat{y}_t^w\right) + \Gamma \sum_{i=0}^{K} n_i var\left(\hat{P}_{i,t}^R - \tilde{P}_{i,t}^R\right) + \sum_{i=0}^{K} \varsigma_i var\left(\hat{\pi}_{i,t}\right) \right], \end{aligned} \tag{14}$$

where $U_C \bar{C}$ has been normalized to 1. The expectation E_0 is calculated at time zero based on all the information available at that date. Its conditionality is based on the initial conditions of the two state variables $\hat{P}_{i,t-1}^R = 0$ and $\tilde{P}_{i,t-1}^R = 0$. The expectation E is obtained by integrating over the stationary distributions of $\tilde{P}_{i,t,-1}^R$.

4.1 The Optimal Plan

The central bank chooses $\left\{\hat{y}_t^w, \hat{\pi}_{i,t}, \hat{P}_{i,t}^R\right\}$ to minimize the welfare function (12) subject to the New Keynesian Phillips curves (9) and the definition of relative prices (10). In this work we let $\varphi_{i,t}$ be the Lagrange multiplier associated with equation (9) and $\psi_{i,t}$ be the

Lagrange multiplier associated with equation (10), and assume the initial conditions $\varphi_{i,-1} = \psi_{i,-1} = \hat{p}_{i,-1} = 0$.

Having solved the optimization problem, we write the equilibrium conditions as a system of first-order stochastic difference equations:

$$A \cdot \hat{x}_{t+1} = B \cdot \hat{x}_t + C \cdot \varepsilon_t,$$

where the column vector $\hat{x}_{t+1}$ contains all the endogenous and exogenous variables of the model $\{\hat{y}^w_{t+1}, \hat{P}^R_{i,t+1} - \tilde{P}^R_{i,t+1}, \hat{\pi}_{i,t+1}, \psi_{i,t}, \tilde{P}^R_{i,t+1}, \hat{P}^R_{i,t}, \varphi_{i,t}\}$, while ε_t is the column vector of regional-specific shocks. The square matrices A and B are functions of the structural parameters of the model. The system is reduced to the following state-space form representation:

$$\hat{x}_t = D \cdot \hat{s}_t$$
$$\hat{s}_t = G \cdot \hat{s}_{t-1} + H \cdot \varepsilon_t,$$

where the column vector $\hat{s}_t$ contains the state variables of the system $\{\tilde{P}^R_{i,t}, \hat{P}^R_{i,t-1}, \varphi_{i,t-1}\}$.

4.2 Inflation Targeting

As mentioned in the previous section, we use the optimal plan as a benchmark to evaluate the performance of alternative inflation-targeting rules. Following Benigno (2004), we focus on two different rules. The first one is a pure inflation-targeting rule where the measure of inflation that the central bank aims to stabilize is the average inflation rate of the K regions, which means

$$\sum_{i=0}^{K} n_i \hat{\pi}_{i,t} = \hat{\pi}^w_t = 0. \tag{15}$$

This measure of inflation resembles the actual goal of the ECB. Equation (15) can be interpreted as the MUICP, which is a weighted sum of the single region's HICP index weighted by the economic size of each region. We compare the welfare loss entailed by this rule with the one obtained under the optimal inflation targeting defined as

$$\sum_{i=0}^{K} \gamma_i^{opt} \hat{\pi}_{i,t} = 0,$$

where the weights γ_i^{opt} are not given by the economic size of the regions but chosen optimally in order to minimize the welfare loss (12) with the following constraints:

$$\gamma_i^{opt} \in [0,1], \quad for\ i = 1....K$$

and

$$\sum_{i=0}^{K} \gamma_i^{opt} = 1.$$

It can be easily shown that if the central bank follows an inflation-targeting rule, the variables $\left\{\hat{y}_t^w, \hat{\pi}_{i,t}, \hat{P}_{i,t}^R\right\}$ can be written as linear combinations of two groups of state variables: the relative prices $\hat{P}_{i,t-1}^R$ and the natural level of relative prices $\tilde{P}_{i,t}^R$. Hence the system of equations under the inflation-targeting assumption becomes

$$\hat{z}_t = D \cdot \hat{z}_{t-1} + H \cdot \varepsilon_t,$$

where $\hat{z}_t$ is the column vector of variables $\left\{\tilde{P}_{i,t+1}^R, \hat{y}_{t+1}^w, \hat{P}_{i,t+1}^R - \tilde{P}_{i,t+1}^R, \hat{\pi}_{i,t+1}, \hat{P}_{i,t}^R\right\}$. All the entries of the square matrix D are zeros, with the exception of the first and the last K columns corresponding to the state variables.

5. Calibration

To simulate the model, we calibrate the structural parameters. The level of price stickiness (α_c and α_s) and the economic sizes of the regions/sectors (n_c and n_s) are calibrated using micro data on price stickiness in Europe as well as the weights used by Eurostat to create the MUICP for regions and the HICP for sectors, as described in section 2 (table 1).

The structural parameters that are common across sectors and regions are calibrated following Benigno (2004) and Rotemberg and Woodford (1997). The intertemporal discount factor (β) is set equal to 0.99, which approximately corresponds to a gross real rate of return (β^{-1}) of 1.01 on average and on a quarterly basis. The degree of monopolistic competition (σ) is set equal to 7.66, which corresponds to a markup of prices over marginal cost of around 15 percent.[10] The risk-aversion coefficient (or the inverse of the intertemporal elasticity of substitution of consumption (ρ)), is set equal to 0.16 as in Benigno (2004).[11] Assuming that the average real wage with respect to variations in production is 0.5 in the euro area,[12] the value of ρ is compatible with an elasticity of labor supply equal to 0.67, which is in line with the micro and macro evidence, as described in Keane and Rogerson (2012). Assuming labor as the only input factor in the production function, such value implies that in the steady-state workers allocate around 60 percent of their time to working activity.

We set the parameter ϕ, which measures the degree of persistence of the Markovian process for the relative price under flexible prices, equal to 0.95 and the variance of the region-specific white-noise shocks σ_ϵ^2 equal to 0.0086^2. This is consistent with the international real-business-cycle literature on the calibration of asymmetric productivity shocks.

6. Results

In this section we present the results of the simulations. We start by considering whether our multi-region model is consistent with the two-region model developed in Benigno (2004). In order to replicate the same calibration exercise as in Benigno (2004), the ten regions are split into two macro regions of approximately equal size. For this purpose it is convenient to include Italy, Austria, Belgium, France, and Portugal in the first macro region, whereas we include Spain, Germany, the Netherlands, Finland, and Luxembourg in the second macro region. In this way the shares of aggregate consumption in these two macro regions work out to about 50.1 percent and 49.9 percent of the total. The size of each macro region is computed as

[10] We also experimented with values between 4 and 11, as in Carvalho (2006) and Nakamura and Steinsson (2008), and results remain robust.

[11] We also try a risk-aversion coefficient equal to 1 as a robustness check.

[12] Rotemberg and Woodford (1997) calibrate a value of 0.47 for the United States. We also try this value for a robustness check.

the sum of the economic sizes of the regions belonging to it, and price stickiness is computed as a weighted average of the stickiness of each country within each macro region, where the weights are given by the economic size of each country (n_r).

In a model with two equal-sized regions, implementing an asymmetric shock to flexible relative prices, such as the one described in section 3.2, turns out to be straightforward, since the shock affecting the two macro regions has the same size and opposite sign. Although the two macro regions have different degrees of price stickiness, the changes in relative prices in the first region mimic exactly the changes in the second region. The same reasoning applies to inflation which has the same size and opposite sign in the two macro regions.

Table 2 reports the welfare reduction, expressed in terms of consumption units, for the three different policies derived in section 4: inflation targeting W_{IT}, optimal targeting W_{OT}, and optimal plan W_{OP}. The deadweight loss reduction (DR) represents the percentage reduction in the deadweight loss that society can obtain by using optimal inflation targeting instead of pure inflation targeting. The percentage reduction is calculated as

$$DR \equiv \frac{E[W_{IT}] - E[W_{OT}]}{E[W_{IT}] - E[W_{OP}]} \times 100.$$

Table 2 shows that optimal targeting outperforms inflation targeting. In fact, the implied welfare reduction measured by the unconditional loss function in equation (14) comes very close to that of the optimal plan. As pointed out in Benigno (2004), when the central bank is allowed to optimally choose the weights, it turns out to be welfare improving to assign higher weights (with respect to its economic size) to the region with more sluggish prices. The bottom panel of table 2 shows that the same applies if we consider sectors instead of regions. Given that price stickiness in the two macro sectors is very dispersed compared with the macro regions, the sector optimal weights turn out to be different from the ones imposed by pure inflation targeting.[13]

[13]Note that when we group together different regions, averaging their price stickiness and economic size, we disregard the differences across regions. However, the analysis is focused on evaluating what happens within each macro region

Table 2. A Two-Region/Two-Sector Model

Regions				
	Economic Size (n_r)	**Shock Proportion (p_r)**	**Price Adjustment ($1-\alpha_r$)**	**Optimal Weights (γ_r^{opt})**
Macro Region 1	50.13	+	15.99	45.03
Macro Region 2	49.87	−	14.02	54.97
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.1035	−0.1021	−0.1021	97.84
Sectors				
	Economic Size (n_s)	**Shock Proportion (p_s)**	**Price Adjustment ($1-\alpha_s$)**	**Optimal Weights (γ_s^{opt})**
Macro Sector 1	50.20	+	6.14	91.73
Macro Sector 2	49.80	−	27.74	8.27
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.1690	−0.0843	−0.0822	97.53

Notes: Macro Region 1: Italy, Austria, Belgium, France, Portugal; Macro Region 2: Spain, Germany, Netherlands, Finland, Luxembourg. Macro Sector 1: restaurants and hotels, housing, furnishing and household equipment, miscellaneous goods and services, processed food. Macro Sector 2: recreation and culture, transport and communications, clothing, unprocessed food, energy. DR: Deadweight loss reduction.

The interaction among variables becomes more complex in a multi-region model. The central bank itself faces a minimization problem where the welfare loss depends on several variables (i.e., aggregate output gap, relative prices, and inflation rates for each region). Moreover, we need to decide how the different regions are

when we take explicitly into account that regions have a different economic size and a different degree of price stickiness. In particular, we are interested in testing whether the "stickiness principle" holds within each macro region or only between the two macro regions.

affected by asymmetric shocks to flexible relative prices. In fact, it differs from a two-region model because there are several alternative patterns of asymmetric shocks that satisfy the condition imposed by equation (11).

In this analysis we assume that half the regions experience a positive shock to their flexible relative price, which means that their relative prices increase, whereas the other half incurs a negative shock, with an implied relative price decrease. We also assume that the shock is uniformly distributed within each macro region.

As pointed out by Benigno (2004), when all regions have the same degree of price stickiness, the optimal weights coincide with the economic size of the regions, and pure inflation targeting leads to the same welfare loss as the optimal plan.[14] When we relax this assumption, we are able to evaluate how the optimal weights change with the degree of price rigidity and the welfare gain implied by optimal inflation targeting.

In tables 3 and 4 we report the results of our multi-region model. In particular, we look, on the one hand, at different combinations of countries belonging to each of the two macro regions. In the top panel of both tables, regions are split into the same macro regions reported in table 2, whereas in the bottom panel of both tables we group the first five more rigid regions together and then the first five more flexible ones. On the other hand, in order to gain more insight into the results, we compare the case in which all regions have the same economic size (table 3) with that in which the observed size of each region is considered (table 4). Observing regions with the same economic size is interesting because it implies that the two macro regions have the same size and consequently are hit by shocks characterized by the same intensity and opposite sign. In other words, the regions in table 3 differ only in their price stickiness and the sign of the shock that affects their relative prices.

Tables 3 and 4 show that, although optimal inflation targeting clearly outperforms inflation targeting in terms of welfare reduction, results on the optimal weights tend to partially contrast with the "stickiness principle," since the optimal weights are not strictly allocated according to the degree of rigidity in the frequency of price

[14] We confirm this result in a multi-region setting.

Table 3. Optimal Weights with Equal Economic Size (regions)

	Economic Size (n_r)	**Shock Proportion (p_r)**	**Price Adjustment ($1-\alpha_r$)**	**Optimal Weights (γ_r^{opt})**
Italy	10.00	+	10.00	26.45
Austria	10.00	+	15.40	1.24
Belgium	10.00	+	17.60	3.09
France	10.00	+	20.90	12.23
Portugal	10.00	+	21.10	9.42
Spain	10.00	–	13.30	13.92
Germany	10.00	–	13.50	11.75
Netherlands	10.00	–	16.20	9.77
Finland	10.00	–	20.30	1.11
Luxembourg	10.00	–	23.00	11.03
Macro Region 1a	50.00	+	17.00	50.60
Macro Region 2a	50.00	–	17.26	49.40
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.0999	−0.0999	−0.0999	97.67
	Economic Size (n_r)	**Shock Proportion (p_r)**	**Price Adjustment ($1-\alpha_r$)**	**Optimal Weights (γ_r^{opt})**
Italy	10.00	+	10.00	57.89
Spain	10.00	+	13.30	0.02
Germaay	10.00	+	13.50	0.02
Austria	10.00	+	15.40	0.03
Netherlands	10.00	+	16.20	10.34
Belgium	10.00	–	17.60	31.70
Finland	10.00	–	20.30	0.01
France	10.00	–	20.90	0.00
Portugal	10.00	–	21.10	0.00
Luxembourg	10.00	–	23.00	0.00
Macro Region 1b	50.00	+	13.68	65.58
Macro Region 2b	50.00	–	20.58	34.42
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.1107	−0.0987	−0.0985	98.79

Notes: Macro Region 1a: Italy, Austria, Belgium, France, Portugal; Macro Region 2a: Spain, Germany, Netherlands, Finland, Luxembourg. Macro Region 1b: Italy, Spain, Germany, Austria, Netherlands; Macro Region 2b: Belgium, Finland, France, Portugal, Luxembourg. DR: Deadweight loss reduction.

Table 4. Optimal Weights with Unequal Economic Size (regions)

	Economic Size (n_r)	**Shock Proportion (p_r)**	**Price Adjustment ($1-\alpha_r$)**	**Optimal Weights (γ_r^{opt})**
Italy	19.89	+	10.00	24.97
Austria	3.25	+	15.40	0.09
Belgium	3.51	+	17.60	0.18
France	21.19	+	20.90	14.96
Portugal	2.29	+	21.10	8.13
Spain	12.49	−	13.30	13.96
Germany	30.00	−	13.50	29.07
Netherlands	5.44	−	16.20	0.21
Finland	1.65	−	20.30	0.09
Luxembourg	0.29	−	23.00	8.33
Macro Region 1a	50.13	+	16.00	45.01
Macro Region 2a	49.87	−	14.02	54.99
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.1026	−0.1007	−0.1007	99.17
	Economic Size (n_r)	**Shock Proportion (p_r)**	**Price Adjustment ($1-\alpha_r$)**	**Optimal Weights (γ_r^{opt})**
Italy	19.89	+	10.00	74.97
Spain	12.49	+	13.30	0.05
Germany	30.00	+	13.50	0.05
Austria	3.25	+	15.40	0.09
Netherlands	5.44	+	16.20	9.48
Belgium	3.51	−	17.60	15.34
Finland	1.65	−	20.30	0.01
France	21.19	−	20.90	0.01
Portugal	2.29	−	21.10	0.01
Luxembourg	0.29	−	23.00	0.00
Macro Region 1b	71.07	+	12.78	83.87
Macro Region 2b	28.93	−	20.50	16.13
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.0469	−0.0398	−0.0397	99.03

Notes: Macro Region 1a: Italy, Austria, Belgium, France, Portugal; Macro Region 2a: Spain, Germany, Netherlands, Finland, Luxembourg. Macro Region 1b: Italy, Spain, Germany, Austria, Netherlands; Macro Region 2b: Belgium, Finland, France, Portugal, Luxembourg. DR: Deadweight loss reduction.

adjustment. In the specific examples that we put forward, the region with the higher degree of price adjustment rigidity within macro regions receives the highest weight. Italy, the most rigid region in table 3 (top panel), holds the highest weight (26.45 percent) and Spain, the most rigid region in the second macro group, holds the second highest weight (13.92 percent), although its price adjustment frequency is higher with respect to other regions. The same pattern emerges in the bottom panel, where the stickiest regions in the two macro regions are Italy (57.89 percent) and Belgium (31.70 percent). The optimal weights are not strictly allocated according to the sluggishness of their price adjustment, even though the less/more sticky macro region/sector receives a lower/higher weight with respect to its economic size, within each group.

The exercise shows that in a context of asymmetric shocks to relative prices, the optimal inflation weights are not exclusively related to price stickiness and economic size, but also to how the shocks are distributed across regions. The optimal weights are sensitive to the composition of the macro regions (top panel versus bottom panel) and to the economic size/shock intensity of the two macro regions (table 3 versus table 4), showing that there is no simple rule of thumb to establish the optimal weights.

Table 5 reports simulations on economic sectors and shows that the results are similar to the regional analysis. We still assume that half of the sectors receive a uniformly distributed positive shock to the flexible relative price and the other half a uniformly distributed negative shock. We include in the first group restaurants and hotels, housing, furnishing and household equipment, miscellaneous goods and services, and processed food, while in the second group we include recreation and culture, transport and communications, clothing, unprocessed food, and energy. Table 5 shows that the most sticky sector in each group receives the highest optimal weight. Interestingly, in line with the findings in the literature that proposes the stabilization of a core price index that excludes goods with a high frequency of price change (Bryan and Cecchetti 1994; Aoki 2001; Cogley 2002; Eusepi, Hobijn, and Tambalotti 2011), we observe that food and energy also receive very low weights in this context. Finally, for sectors, the welfare gain due to optimal inflation targeting is also high.

Table 5. Optimal Weights with Unequal Economic Size (sectors)

	Economic Size (n_s)	**Shock Proportion (p_s)**	**Price Adjustment ($1-\alpha_s$)**	**Optimal Weights (γ_s^{opt})**
Restaurants and Hotels	30.30	+	4.20	63.27
Housing	2.70	+	6.50	0.24
Furnishing and Household Equipment	5.00	+	7.20	0.19
Miscellaneous Goods and Services	4.80	+	7.30	0.19
Processed Food	7.40	+	12.50	9.40
Recreation and Culture	6.50	–	6.60	0.42
Transport and Communications	8.50	–	7.20	1.00
Clothing	16.20	–	8.40	24.70
Unprocessed Food	7.80	–	37.20	0.58
Energy	10.80	–	78.80	0.01
Macro Sector 1a	50.20	+	6.14	91.74
Macro Sector 2a	49.80	–	27.74	8.26
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.151	−0.0834	−0.0834	99.99
	Economic Size (n_r)	**Shock Proportion (p_r)**	**Price Adjustment ($1-\alpha_r$)**	**Optimal Weights (γ_r^{opt})**
Restaurants and Hotels	30.30	+	4.20	79.89
Housing	2.70	+	6.50	0.17
Recreation and Culture	6.50	+	6.60	0.17
Furnishing and Household Equipment	5.00	+	7.20	0.73
Transport and Communications	8.50	+	7.20	0.44
Miscellaneous Goods and Services	4.80	–	7.30	3.50
Clothing	16.20	–	8.40	15.01
Processed Food	7.40	–	12.50	0.01
Unprocessed Food	7.80	–	37.20	0.07
Energy	10.80	–	78.80	0.01
Macro Sector 1b	53.00	+	5.38	94.72
Macro Sector 2b	47.00	–	29.89	5.28
	Inflation Targeting	Optimal Targeting	Optimal Plan	DR
Welfare Reduction	−0.1523	−0.0738	−0.0738	99.99

Notes: Macro Sector 1a: restaurants and hotels, housing, furnishing and household equipment, miscellaneous goods and services, processed food; Macro Sector 2a: recreation and culture, transport and communications, clothing, unprocessed food, energy. Macro Sector 1b: restaurants and hotels, housing, recreation and culture, furnishing and household equipment, transport and communications; Macro Sector 2b: miscellaneous goods and services, clothing, processed food, unprocessed food, energy. DR: Deadweight loss reduction.

7. Concluding Remarks

This paper investigates optimal inflation targeting for the euro area using a multi-region model with asymmetric demand shocks. The analysis shows that in a multi-region context the optimal weights result from complex interactions between the degree of price stickiness, economic size, and the distribution of the shocks within regions. A similar result holds when we use the model to match the different degrees of nominal price rigidities across sectors. Therefore, assigning higher weights to the regions or sectors with a higher degree of nominal rigidities is not necessarily the optimal policy, and there is no simple rule of thumb that the central bank can follow to guide the choice of the optimal weights. Simulations show that the welfare gain from choosing the weights optimally may be substantial compared with a pure inflation-targeting regime that weights each regional inflation rate according to the economic size of the region.

The analysis shows that further progress is needed for a comprehensive assessment on the welfare consequences of heterogeneity in nominal rigidities across regions and sectors. For instance, it would certainly be interesting to extend the model with a segmented labor market, reflecting the limited labor mobility in Europe. In addition, the analysis should also be extended to investigate other sources of heterogeneity such as heterogeneity in the labor shares or in the shocks disturbing each region and sector. Our paper particularly investigated the effect of asymmetric demand shocks that move relative prices across regions; however, more analysis is needed to extend the number of shocks included in the model to study their effect on the optimal weights and enable an empirical evaluation of the structural model. These investigations remain open for future research.

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