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Abstract

In a monetary union, inflation rate differentials may be substantial over the business cycle. This paper parameterizes a two-country monetary union in which different economic structures in the two countries generate temporary inflation differentials. Cross-country differences are introduced in (i) the elasticity of demand in the goods markets, which cause producers to discriminate prices, (ii) the degree price inertia and (iii) openness or preference for foreign goods in consumption. The model is calibrated to reproduce two average big EMU countries and it is able to generate sizeable inflation differentials. We find the mechanism of price discrimination quantitatively more important than the differences in price inertia. Moreover, under asymmetric shocks, differences in the degree of openness as the ones observed within the EMU can have sizeable effects on the dispersion of inflation rates.

1. Introduction

Changes in relative prices in a monetary union, i.e. inflation differentials, may not disappear despite the fixed exchange rate. In September 2002 the difference between the maximum and the minimum HICP inflation rate in the euro area countries was about 3.5 percentage points. Indeed the dispersion, measured as the standard deviation of the inflation rates across euro area countries, is around 1 per cent and has remained very persistent since the beginning of EMU in spite of the changes in the level of inflation (see Figure 1).

Observed inflation differentials can be due to the convergence processes enhanced by economic integration that vanish in the long run, such as convergence in price levels associated with productivity catching-up (the Balassa(1964)-Samuelson(1964) effect) and income levels convergence. Nevertheless, empirical evidence (see Rogers, 2002) shows that during the nineties factors other than price convergence explain most of the cross-country inflation differences in Europe.[1]

In the present paper, we analyze potential sources of inflation differentials among members of a monetary union beyond those associated with income and price convergence. Differences in economic structures, such as the degree of competition, openness or the intensity of nominal inertia, may also generate cross-country inflation differentials even in response to common shocks. We explore this alternative explanation to account for the EMU evidence. Our aim is to explain inflation differentials that are relevant at business cycle frequencies and, therefore, we focus on the differential of the short run response of inflation to shocks across countries. To that end, we set up a simple general equilibrium model of a two-country monetary union, calibrated to mimic the features of representative European economies. We perform simulation exercises to analyze the effects of common and asymmetric shocks, for alternative values of some crucial parameters of the model. Our work is akin to Chari, Kehoe and McGrattan's

[1] Country case studies (see Estrada and Lopez Salido, 2002, for Spain) and Euro area comparisons for the largest economies (Ortega, 2003) also show that during the years prior to EMU convergence processes such as the Balassa-Samuelson hypothesis have not necessarily been the major factor behind the changes in relative prices across countries.

(2001), who look at the persistence and volatility of deviations from the law of one price among tradeable goods between US and Europe and Bergin (2001), who studies the deviations from purchasing power parity in a monetary union.[2]

The economics of inflation differentials in this model is simple: inflation reacts faster in countries with more competitive markets and with lower price adjustment costs. This simple structure is able to generate substantial inflation differentials for reasonable parameter values. Small deviations in the degree of competition that account for 5 per cent long run price level difference across countries may be responsible for temporary inflation differentials of up to 28 basis points when the economy is subject to a common monetary policy shock. That may represent up to one fourth of the actual inflation dispersion in the euro area countries. Moreover, cross-country realistic differences in the degree of nominal inertia and/or in openness also contribute to generate substantial inflation differentials in presence of regional shocks. For example, if the domestic country is very open its inflation rate may respond even more than the foreign inflation rate to shocks originating abroad, depending of the type of disturbance.

The paper is organized as follows. Section 2 outlines the model. The calibration, in section 3, reproduces some long-term features in the European economy. Section 4 contains the main results of the paper that are presented in terms of impulse responses and of alternative price dispersion statistics. These are calculated under common and asymmetric shocks as well as under alternative values for the relevant parameters. Section 5 concludes.

2. The model

The model is a fixed exchange rate version of Obstfeld and Rogoff's (1995) in which the world is composed of two countries with a common monetary authority. The model incorporates two special features.

[2] Unlike Bergin (2001), who uses translog preferences, we stick to a CES specification of consumption goods with firms facing different elasticities of demand across countries.

First, all goods are tradeable. We are aware that inflation in the traded sector across Euro area countries is significantly lower than in the non-traded one. In September 2002, the difference between the maximum and the minimum HICP inflation rate for non-energy industrial goods was of 2.85 percentage points, while it was 5.20 percentage points for services. If sizeable inflation differentials emerge for reasonable parameterizations of shocks and economic structures across EMU countries in this model, then we should expect that those same shocks and structures would generate higher inflation differentials when considering the non-traded sector. In a sense, we are aiming at modeling and quantifying a lower bound for inflation differentials in EMU at business cycle frequencies. In fact, as shown in Figure 1, the actual inflation dispersion of industrial (non-energetic) goods is somewhat lower adn as persistent as the ones observed with the overall HICP.

Second, the model allows for heterogeneity of market power across countries that tries to capture institutional and regulatory differences as well as different preferences for the variety of goods within the monetary union. This generates optimal price discrimination by firms and will cause permanent deviations of the law of one price.[3]

The empirical motivation for this key property of the model is the observation that although there has been a significant price convergence process across European countries, deviations from the law of one price remain large and persistent among EMU countries both for specific goods (Goldberg and Verboven, 2001, for the car industry) and for a basket of goods (Rogers, 2002); this also occurs among cities and regions in well established monetary unions (see, for example, Cecchetti, Mark and Sonora, 2000, for the US).

2.1. Market Structure

Let us consider a world of two countries: Home (H) and Foreign (F). Agents populating country H are indexed by j ($j \in [0, 1]$), each of whom produces a

[3] An alternative to price discrimination discussed recently by the literature is that the traded sector contains a large share of non-traded intermediate inputs, such as transport, storage and communication (e.g. Burstein, Neves and Rebelo (2000), Corsetti and Dedola (2001)).

variety of one type of tradeable intermediate good ($y_t(j)$) in which the country is specialized. Each agent sells part of her production in the domestic market ($y_{H,t}(j)$) and the rest in the foreign market ($y^*_{H,t}(j) = y_t(j) - y_{H,t}(j)$); she enjoys some monopolistic power both at home and abroad.

Either due to different regulations or preferences, the elasticity of substitution among brands is different across countries. The elasticity of substitution is country specific, but not product specific and takes the value of θ for those varieties sold in H, and θ^* for those sold in F. Thus, producers can discriminate prices across countries, and they optimally do so. Neither consumers are not allowed to arbitrage across markets nor firms' entry and exit are permitted in domestic or foreign markets.

In each country there is a sector of final goods selling products at home and abroad (exports). This sector is represented by two CES aggregators. Aggregator H buys varieties produced in the domestic country ($y_{H,t}(j)$) and sells a composite product to home consumers. These varieties are imperfect substitutes in consumer preferences:

$$y_{Ht} = \int_0^1 \left(y_{H,t}(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}$$

The demand function for each variety derived from the aggregator problem is the following

$$y_{H,t}(j) = y_{H,t} \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\theta} \tag{2.1}$$

and, imposing the zero profit condition, the utility-based price index is given by $P_{H,t} = \int_0^1 \left(P_{H,t}(j)^{1-\theta} dj \right)^{\frac{1}{1-\theta}}$. Similar relationships are obtained for the home aggregator of $y^*_{H,t}$ (exports) and for the aggregators for country F : $y^*_{F,t}$ for foreign domestic consumption and $y_{F,t}$ for foreign exports (to the H country)

2.2. Preferences and price formation

Agent j sells her own variety of intermediate goods produced at home and abroad, and uses the revenues to consume both domestic and foreign goods. She will seek to maximize the utility of consumption and minimize the disutility of production.[4]

The consumption basket is represented by the CES aggregator,

$$c_t(j) = \left[\omega_{H,t}\left(c_{H,t}(j)\right)^{\rho} + \omega_{F,t}\left(c_{F,t}(j)\right)^{\rho}\right]^{\frac{1}{\rho}}$$

where $c_{H,t}(j)$ is the consumption by H residents of H produced goods, $c_{F,t}(j)$ is the consumption by H residents of F produced goods, ω_H and ω_F are their respective trade-based weights in the consumption bundle and $\varepsilon = \frac{1}{1-\rho}$ is the elasticity of substitution among both goods. The more open the economy the larger the share of foreign goods in the consumption basket, i.e. higher $\frac{\omega_F}{\omega_H}$, and the higher the elasticity of substitution between home and foreign goods.

Agent j also sells her output in monopolistically competitive markets: she sets the nominal price, $P_{H,t}(j)$ and $P^*_{H,t}(j)$, subject to the requirement that it satisfies the demand for final goods. Moreover, the agent faces a quadratic cost of adjusting prices (as in Rotemberg, 1982).

The constrained maximization program of the home producer-consumer agent j consists therefore of maximizing her lifetime utility,

$$U_t(j) = E_t \sum_{t=0}^{\infty} \beta^t s_t \left[\frac{c_t(j)^{1-\sigma}}{1-\sigma} - \frac{[y_t(j)v_t]^{\alpha}}{\alpha}\right] \tag{2.2}$$

subject to

$$\begin{aligned} & A_t(j) + P_{H,t}c_{H,t}(j) + P_{F,t}c_{F,t}(j) + P_{H,t}AC_{H,t}(j) + P^*_{H,t}AC^*_{H,t}(j) \\ \leq \; & \left(r_{t-1} - \psi\left(e^{a_{t-1}} - 1\right)\right)A_{t-1}(j) + P_{H,t}(j)y_{H,t}(j) + P^*_{H,t}(j)y^*_{H,t}(j) \end{aligned}$$

and the demand functions (2.1) (along with the corresponding demands for $y^*_{H,t}(j^*)$), where s_t is a preference shock, v_t is an innovation to the disutility of production that stands by a negative supply shock, and

[4] Since we focus on price dynamics we abstract from the labor market and we choose to feature the representative agents as yeoman farmers, simultaneously engaged in consumption and production. Woodford (2002) shows that the equilibrium in this economy is the same as one in which the representative agent decides her labor supply and where the labor market is competitive.

$$AC_{H,t}(j) = \frac{\phi y_{H,t}}{2} \left(\frac{P_{H,t}(j)}{P_{H,t-1}(j)} - \bar{\pi} \right)^2 \tag{2.3}$$

$$AC^*_{H,t}(j) = \frac{\phi y^*_{H,t}}{2} \left(\frac{P^*_{H,t}(j)}{P^*_{H,t-1}(j)} - \bar{\pi} \right)^2 \tag{2.4}$$

represent the costs of adjusting prices in each market expressed in units of the aggregate bundle, scaled by a country specific factor ϕ.[5] This convex cost function is just an abstraction and tries to represent the variety of reasons why a firm decides not to change its price instantaneously at each period. That cost function generates similar dynamic implications that the alternative specification of staggered prices but it has no long-run implications for inflation.

A_t is the nominal amount held by residents in H of an uncontingent international bond that yields a nominal gross return r_t in the world financial market. We include the function $\psi_t = \psi \left(e^{a_t} - 1 \right)$ to represent a transaction cost of holding assets. The cost function depends on the ratio of asset holdings to consumption (i.e. $a_t = \frac{A_t}{P_t c_t}$) such that if the household is a lender, her returns are reduced by the amount of the cost $(-\psi \left(e^{a_t} - 1 \right) < 0)$, conversely, if the household is a net borrower, then interest payments are increased by $(-\psi \left(e^{a_t} - 1 \right) > 0)$. This transaction costs function guarantees that the model is stationary in presence of transitory shocks.[6]

A similar problem holds for the foreign representative household, j^*, where $c^*_{F,t}(j^*)$ is the consumption by F residents of F produced goods and $c^*_{H,t}(j^*)$ is the consumption by F residents of H produced goods. The scale factor for the costs of adjusting prices in the foreign country is ϕ^*, which allows for exploring the

[5] It is more consistent with the individual firm's problem to define the cost function in terms of individual forgone output instead of the aggregate output. Nevertheless to do this it would only generate more complex dynamics of the firm's optimal price equation so we prefer the standard way followed in the macro literature.

[6] See Benigno (2001). Schmitt-Grohé and Uribe (2001) explore alternative ways to remove non-stationarity in open economy models with incomplete markets, stemming from the accumulation of foreign assets, and find that all produce similar conditional and unconditional correlations.

implications of different degrees of price stickiness in different countries in as long as ϕ^* differs from ϕ. Foreign agents face also a similar transaction cost function.

The following aggregate goods market clearing condition is imposed for y_{Ht}

$$\int_0^1 c_{H,t}(j)dj + \int_0^1 AC_{H,t}(j)dj = c_{H,t} + AC_{H,t} = y_{H,t} \tag{2.5}$$

and similar ones for the exports market, y^*_{Ht}, the foreign domestic goods market, y^*_{Ft}, and foreign exports market, y_{Ft}.

The model is closed with the specification of the balance of payments and the common monetary policy. The balance of payments constraints in both countries are expressed as:[7]

$$P^*_{H,t}c^*_{H,t} + \left(r_{t-1} - \psi\left(e^{a_{t-1}} - 1\right)\right)A_{t-1} - P_{F,t}c_{F,t} = A_t \tag{2.6}$$

$$A_t = -A^*_t \tag{2.7}$$

The common monetary policy is modeled as a standard Taylor interest rate rule where the central bank cares only for inflation. The monetary authority sets the nominal interest rate to prevent deviations of aggregate inflation from its steady state value, and to ensure that the nominal interest rate moves smoothly. Both countries are assumed to have equal size and therefore the weight of each country's variable is $\frac{1}{2}$.[8] In log-linear form, the rule is represented by the following expression, in which $z_{r,t}$ represents unexpected monetary policy changes,

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1-\rho_r)\rho_\pi \frac{1}{2}\left(\widehat{\pi}_t + \widehat{\pi}^*_t\right) + z_{r,t}. \tag{2.8}$$

[7] To rationalise the existence of transaction costs we assume that there is a financial intermediary that gets those payments as revenues in exchange for the services of financial intermediation. Further, we assume that this financial firm is owned by residents of the foreign country so that total revenues for the foreign consumer budget constraint are augmented by $\left[\psi^*_t A^*_{t-1} + \psi_t A_{t-1}\right]$.

[8] This kind of monetary policy rule may not approximate the optimal policy, especially when the degree of price rigidity differs across countries (see Benigno and López-Salido (2002)).

2.3. Equilibrium inflation dynamics

The log-linear version of the symmetric monopolistic equilibrium is summarized in the Appendix.[9] It is obtained upon aggregation of the first order conditions of the representative consumer-producer agents at home and abroad, the market clearing conditions, the monetary policy rule and the balance of payments constraints in both countries.

The domestic aggregate consumption price index depends on the home-bias, measured by the weight of consumption of domestic goods (ω_H) relative to weight of imported goods (ω_F), and on the elasticity of substitution parameter (ρ),

$$\widehat{P}_t = (\omega_H)^{\left(\frac{1}{1-\rho}\right)} \left(\frac{P_H}{P}\right)^{\left(\frac{\rho}{\rho-1}\right)} \left(\widehat{P}_{H,t}\right) + (\omega_F)^{\left(\frac{1}{1-\rho}\right)} \left(\frac{P_F}{P}\right)^{\left(\frac{\rho}{\rho-1}\right)} \left(\widehat{P}_{F,t}\right) \tag{2.9}$$

and an equivalent expression holds for the foreign country price index P_t^*.

Since our aim is to explain the inflation differentials at business cycle frequencies, we need to pay special attention to the two aggregate inflation equations:

$$\widehat{\pi}_t = \beta E \widehat{\pi}_{t+1} + \frac{\tau(\theta-1)}{\phi \overline{\pi}^2} \left[\widehat{d}_t + \frac{(1-\tau)\phi}{\tau \phi^*} \left(\widehat{d}_t^* + \left(\widehat{P}_{Ft}^* - \widehat{P}_{Ft} \right) \right) \right] \tag{2.10}$$

$$\widehat{\pi}_t^* = \beta E \widehat{\pi}_{t+1}^* + \frac{(1-\tau^*)(\theta^*-1)}{\phi^* \overline{\pi}^2} \left[\widehat{d}_t^* + \frac{\tau^* \phi^*}{(1-\tau^*)\phi} \left(\widehat{d}_t + \left(\widehat{P}_{Ht} - \widehat{P}_{Ht}^* \right) \right) \right] \tag{2.11}$$

where $\frac{(1-\tau)}{\tau} = \left(\frac{\omega_F}{\omega_H}\right)^{\left(\frac{1}{1-\rho}\right)}$, $\frac{\tau^*}{(1-\tau^*)} = \left(\frac{\omega_H^*}{\omega_F^*}\right)^{\left(\frac{1}{1-\rho}\right)}$ and

$$\widehat{d}_t = \sigma \widehat{c}_t + (\alpha - 1)\widehat{y}_t + \frac{\omega_F}{(1-\rho)} \left(\frac{\overline{c}_F}{\overline{c}}\right)^{\rho} \left(\widehat{P}_{F,t} - \widehat{P}_{H,t} \right) + \alpha \widehat{v}_t$$

$$\widehat{d}_t^* = \sigma \widehat{c}_t^* + (\alpha - 1)\widehat{y}_t^* + \frac{\omega_H^*}{(1-\rho)} \left(\frac{\overline{c}_H}{\overline{c}}\right)^{\rho} \left(\widehat{P}_{H,t}^* - \widehat{P}_{F,t}^* \right) + \alpha \widehat{v}_t^*$$

[9] Variables with $\widehat{\ }$ represent log-deviations with respect to their steady state value, whereas a_t and a_t^* are expressed in absolute deviations from the steady state.

These expressions are straightforward extensions of the standard closed economy new Keynesian Phillips curve.[10] Thus, $\widehat{d}_t$ represents the open economy equivalent to the domestic real marginal cost of production in the yeoman farmer economy as defined by Woodford (2002), i.e. the marginal disutility of production in units of an equivalent quantity of the consumption aggregate. Similarly, $\widehat{d}_t^*$ represents the real marginal cost in the foreign economy. Domestic and foreign real marginal costs affect domestic inflation through their effect upon $\widehat{\pi}_{H,t}$ and $\widehat{\pi}_{F,t}$ respectively. Since the disutility of production is measured in terms of a consumption aggregate that includes imported goods, the marginal cost depends on relative prices. Improvements in the terms of trade, $(\widehat{P}_{F,t} - \widehat{P}_{H,t})$, increase the domestic marginal cost by inducing a substitution away from foreign to home produced goods. Similarly, $\widehat{\pi}_{F,t}$ responds to $(\widehat{P}^*_{H,t} - \widehat{P}^*_{F,t})$. An additional term in our model, $(\widehat{P}^*_{Ft} - \widehat{P}_{Ft})$, captures the effect of price discrimination. Increases in $\widehat{P}^*_{Ft}$ relative to $\widehat{P}_{Ft}$ generates a wealth transfer from the foreign to the home country that also rises the implicit wage and the marginal cost at home.

In an two-country world, this simple structure makes it also possible to represent the incidence of the price setting mechanism in the dynamics of inflation differentials through the elasticities of demand (θ, θ^*) as well as through the price inertia parameters (ϕ, ϕ^*). Moreover, the parameters that govern the degree of openness $(\omega_H, \omega_F, \omega^*_H, \omega^*_F, \rho)$ will also affect the relative price dynamics.[11]

Inflation rates respond differently to shocks originating at home and abroad. A shock originated at home translates quicker to inflation the higher the elasticity of substitution faced by the producer (θ), the lower the cost of adjusting prices at home (ϕ) and the higher the home consumption bias, i.e. the lower the openness $(\frac{\omega_F}{\omega_H})$ and the cross-country substitutability of consumption goods. If the shock is

[10] The closed economy case can be easily recovered (for the domestic country) making $\tau = 1$ $(\omega_F = 0)$,

$$\widehat{\pi}_t = \beta E\widehat{\pi}_{t+1} + \frac{(\theta - 1)}{\phi\bar{\pi}^2}\left(\sigma\widehat{c}_t + (\alpha - 1)\widehat{y}_t + \alpha\widehat{v}_t\right)$$

where $\sigma\widehat{c}_t + (\alpha - 1)\widehat{y}_t + \alpha\widehat{v}_t$ represents the real marginal cost.

[11] It is assumed that the steady state inflation rate $\bar{\pi}$ is the same in both economies.

originated abroad its effect is larger the higher the degree of openness, the higher the elasticity of substitution ($\frac{1}{1-\rho}$) and the lower price inertia abroad (ϕ^*).

Even shocks that are common to domestic and foreign real marginal costs, in particular innovations to the common monetary policy, may cause disparities in the inflation rates if the degree of market competition, of price inertia or of openness differ across countries. Inflation differentials will be larger (in absolute value $|\widehat{\pi}_t - \widehat{\pi}_t^*|$) the larger the gap between θ and θ^* and between ϕ and ϕ^*.

2.4. Discussion of alternative price setting mechanisms

Since the different inflation response across markets to common or idiosyncratic shocks is a key feature of our approach, the choice of the price setting mechanism is not only a matter of analytical convenience. Although the above dynamic specification of inflation is common to the new Keynesian Phillips curve in an open economy setting (e.g., Galí and Monacelli, 1999), the fact that the slope of the Phillips curve is an increasing function of the elasticity of demand (θ) is not. This feature comes out naturally in the model of convex adjustment costs. Firms compare the opportunity cost of not adjusting the price to its optimum level after a shock, with an increasing marginal cost of changing the level of prices. This produces an optimal rate of adjustment that will be faster for those firms for which profits are more sensitive to deviations from the optimal policy. This sensitivity depends on the curvature of the profit function that is a function of the elasticity of demand. Thus, firms operating in a highly competitive environment will experiment a substantial opportunity cost if the price deviates from its profit maximizing level, whereas this cost will be of second order for firms with high monopoly power (Akerloff and Yellen, 1984; Martin, 1993).

Staggered price models, in which firms revise their prices at exogenously given intervals, yield a rather different implication. For example, Gali, Gertler and López-Salido (2001) and Sbordone (2002) show, under the stochastic Calvo (1983) setup and some assumptions about technology, that the response of inflation to exogenous shocks depends negatively on the elasticity of demand. When firms change prices at exogenously given points in time, the logic of the comparison between the cost of changing and that of no changing prices does no longer apply. When the opportunity of changing prices comes, the firm does not care about the losses made during the period of no action; rational firms will look into the future trying to avoid large deviations of the marginal revenue from the expected path of the marginal cost. Thus, firms facing highly elastic demand curves will need smaller price adjustment to bring the marginal revenue back on line with the marginal cost, i.e. the optimal price of these firms barely changes with expected movements in the marginal cost. Conversely, other things being equal, less competitive firms will find it optimal to proceed to a larger change in the price level.

In fact these opposite results in alternative price setting models can be made compatible. We must bear in mind that it is the exogeneity of the spell of price stability by firms what is driving the implication of faster adjustment by more ceompetitive firms. This assumption is very helpful in order to generate a tractable dynamic equation for aggregate inflation, but is also the less satisfactory feature of this class of models. If we remove the assumption of exogenously fixed intervals, it might be the case that less competitive firms would proceed to change prices more often, although less intensively, than more competitive ones, thus generating more price inertia (Blanchard and Fischer, 1989).[12]

Thus, a negative correlation between market competition and price stickiness is a fairly general implication of the literature of price inertia. The empirical evidence is not unequivocal, but several papers find that price stickiness is lower for firms operating in more competitive markets (see, e.g.,Carlton, 1986, Geroski, 1995, Hall, Walsh and Yates, 2000 and Bils and Klenow, 2002). Interestingly, Carlton (1986) goes beyond that and reports evidence of more intense but less frequent adjustment of prices by firms operating in less competitive markets, which would suggest that staggered pricing gives a correct but incomplete picture of the link

[12] Using a simple Ss model those authors show that the threshold for the exogenous shock beyond which the firm will adjust prices is negatively related to the elasticity of demand. Thus, more competitive firms will tend to change prices more often.

between market structure and inflation dynamics.

3. Calibration

This section discusses the calibration of the parameters and the steady state relationships that affect the coefficients of the log-linear model presented in the Appendix. The benchmark calibration represents two average big Euro area countries, moderately open, but one economy being more competitive than the other. We are also interested in analyzing how changes in the degree of price inertia and in the degree of openness for one of the countries affects the results. Finally, we parameterize the sources of fluctuations needed for the alternative conditional exercises performed in the next section.

3.1. Price discrimination.

To calibrate the parameters related to the price discrimination mechanism we rely on recent evidence that reports large deviations from the law of one price in the long run despite the significant price level convergence occurred across EMU countries, especially in the traded sector.

Goldberg and Verboven (2001) find convergence towards the law of one price in the European car market although significant fixed effects in the convergence equation indicate systematic price differentials across countries. Their measured long-term price differences take values between 5 and 17 per cent and are highly significant. Rogers (2002) also reports differences in individual items and in a composite price level for 18 cities in all Euro area countries, and compares them to the dispersion of the same prices across 13 US cities. These results are summarized in Table 1 where the standard deviation across cities in US and the Euro area for 1990 and 2001 are reported. Even in a long lasting monetary union, such as the US, price level differences persist in the long run; their evolution indicates that there is a limit to price convergence of about 5 per cent differences in the price levels in the traded sector. There has been a very significant price convergence during the nineties for traded goods in the Euro area and the current price dispersion of 6 per cent price differences across locations is similar to the one observed for US. Non-tradables prices are much more dispersed both in the Euro area and especially in the US.

Table 1

Price level dispersion across locations			
CPI-weighted indexes			
	Composite price	1990	2001
Euro Area	Non-tradeables	0.15	0.12
	Tradeables	0.18	0.06
US	Non-tradeables	0.31	0.40
	Tradeables	0.04	0.05

Source: Rogers (2002), Figures 1 and 2.

In our model, the elasticities of substitution across varieties sold in each country (θ, θ^*) determine the steady state markups ($\frac{\theta}{\theta-1}$ and $\frac{\theta^*}{\theta^*-1}$, respectively), and hence the size of price level differences in the long run. If these elasticities are different, home producers will markup differently those products sold at home and abroad

$$\left(\frac{\overline{P_H^*}}{P_H}\right) = \frac{\frac{\theta^*}{\theta^*-1}}{\frac{\theta}{\theta-1}} \neq 1 \tag{3.1}$$

and the same will hold for $\left(\frac{\overline{P_F^*}}{P_F}\right)$. We consider the domestic country as the most competitive one, with a markup of 1.1 (i.e. a net markup of 10 per cent), lower than that in the foreign country which is calibrated to be 15 per cent in line with Basu and Fernald's (1997) evidence. These values imply a conservative estimation of the importance of markup differences across European markets. The markup ratio of 15 to 10 per cent implies a permanent price level differential of around 4.5 per cent, slighthly lower than the estimations in Rogers (2002) for European tradeable goods and close to the lower bound of car price differences in Europe reported by Goldberg and Verboven (2001).

3.2. Preferences

The preference parameters are taken from the business cycle literature. The annual discount factor β is 0.99 to set an annual real interest rate of 3 per cent. The ratio $\psi/\overline{r}$ is set to 10^{-3} to approximate the cost of intermediation in the financial markets, as in Benigno (2001).

The risk aversion parameter, σ, is 2. The output elasticity parameter α (equation 2.2) has a correspondence with the parameters in a decentralized setup with separable consumption-labor preferences and a decreasing returns to labor production function. If α_L is the labor share and χ is the inverse of the labor supply elasticity then $\alpha = \frac{(1+\chi)}{\alpha_L}$. Taking the average labor share in the Euro area of 0.75 and assuming a value for the labor supply elasticity of $1/\chi = 0.2$, we obtain a calibrated value for α of 8.[13] Since the chosen labor supply elasticity is more consistent with micro evidence, we also perform sensitivity analysis on the model simulations using a larger value ($1/\chi = 1$), more according with macro calibrations.

3.3. Openness

The following steady state equations are derived from the equations describing the equilibrium:

$$1 = \frac{\overline{c}_H}{\overline{y}} + \frac{\overline{c}_H^*}{\overline{y}} \tag{3.2}$$

$$\left[\left(\frac{P_F}{P_H}\right)\frac{\omega_H}{\omega_F}\right]^{1/(1-\rho)} = \frac{\overline{c}_H}{\overline{c}_F} \tag{3.3}$$

Table 2 shows the most relevant ratios for each EMU country in the period 1991-2001 that are used to calibrate the above expressions.[14]

[13] The average labor shares in the 1991-2000 period are 0.79 for Germany, 0.70 for France and Italy and 0.76 for Spain.

[14] The source is Eurostat annual national accounts. Data availability has forced us to take a shorter sample size starting in 1995 for Greece. The consumption of home produced goods, $\overline{c}_H$,

Table 2

Average ratios across Euro area countries: 1991-2001			
	$\frac{\bar{c}_H}{\bar{c}_F}$	$\frac{\bar{c}_H}{\bar{y}}$	$\left(\frac{P_F}{P_H}\right)$
Belgium	0.47	0.32	1.18
Germany	2.84	0.74	1.03
Greece	2.81	0.73	0.96
Spain	3.30	0.76	0.99
France	3.54	0.78	1.04
Ireland	0.35	0.26	0.69
Italy	3.17	0.76	0.90
Netherlands	0.85	0.46	1.05
Austria	1.50	0.60	1.05
Portugal	1.86	0.65	1.03
Finland	2.12	0.68	0.95

We have calibrated our economies to represent the average big Euro area country such as Germany, France, Italy or Spain. Thus, we take as benchmark calibration $\frac{\bar{c}_H}{\bar{c}_F} = 3$ and $\frac{\bar{c}_H}{\bar{y}} = 0.75$ representing a moderately open economy. Notice that this calibration would hold for large Euro area countries but also for some small ones (i.e. Greece). The parameters that measure the share of home produced goods and imports in total consumption, ω_H and ω_F, respectively, are calibrated using the expression (3.3) and assuming that $\left(\frac{P_F}{P_H}\right) = 1$. The last column in Table 2 indicates that actual deviations of this ratio from the assumed parity have been minimal. The elasticity of substitution $\varepsilon = \frac{1}{1-\rho}$ is fixed to 1.5, the value used by Backus, Kehoe and Kydland (1994). We shall also consider different values of ρ, ranging from a unit elasticity ($\rho \simeq 0$) to an elasticity $\varepsilon = 4$ ($\rho = 0.75$).

We assume that the steady state nominal net asset position for each country, A, is zero and that both countries have the same size ($\frac{\overline{P}}{\overline{P}^*}\frac{\bar{c}}{\bar{c}^*} = 1$). Thus, net

is approximated by the sum of private and government final consumption expenditure plus gross fixed capital formation and changes in inventories minus imports of goods and services. The ratio $\frac{\bar{c}_H}{\bar{c}_F}$ is measured by the average share over the period of consumption of domestic goods to imports.

exports are zero at the steady state,

$$\left(\frac{\overline{P_H^*}}{P_F}\right) = \frac{\overline{c}_F}{\overline{c}_H^*} \tag{3.4}$$

Sensitivity exercises are carried out in Section 4 in order to explore the incidence of allowing for different degree of openness and size across countries.

3.4. Nominal stickiness and the monetary policy rule

The price inertia parameters ϕ and ϕ^* have been set to 100 to generate a slope of the Phillips curve, $\frac{\tau(\theta-1)}{\phi\overline{\pi}^2}$, equal to 0.10. A 10 per cent response of inflation to a unit change in the real marginal cost corresponds to the estimations in Benigno and López-Salido (2002) for France and Germany. We also perform sensitivity analysis on this parameter consistently with the estimates of the Phillips curve for other European countries.

The monetary policy rule displays interest rate smoothing ($\rho_r = 0.8$), no output response and the inflation response coefficient is $\rho_\pi = 1.5$. That parameterization of the Taylor rule is consistent with recent Euro area estimates (e.g. Andrés, López-Salido and Vallés, 2001).

3.5. Shocks

Finally, we analyze the magnitude of the inflation differentials and the volatility of the relative prices under a common (monetary policy) shock and two asymmetric shocks: a positive foreign preference or demand shock and a negative foreign supply shock.

We assume that the asymmetric shocks follow AR(1) processes with persistence parameter 0.9. The sizes of the three shocks have been calibrated to reproduce in each case the volatility of output observed on average for the big Euro area countries, Germany, France, Italy and Spain, i.e. $std(y) = 0.8$ (see Table 3 in the next section). A standard deviation of 0.7 per cent in the monetary policy shock generates a volatility of 0.8 per cent in domestic output, while the standard deviation of the foreign demand and supply shocks have been calibrated to 7.2 and 0.5 per cent, respectively, to generate the same standard deviation of foreign output.

4. Simulation Results

In this section we make a quantitative assessment of the changes in relative prices predicted by the model under different shocks, as well as the sensitivity of those predictions to the key parameters that govern the dynamics of inflation. We compute the response of output and prices to a given shock, either symmetric or asymmetric, focusing on the short run response of the inflation differential between the two countries. We also compute two other measures of price dispersion: first, the the standard deviation of the inflation response across countries[15]; second, the business cycle volatility of the relative consumption-based national price indexes measured with the ratio of the standard deviation of relative prices to the standard deviation of one country's output.

4.1. Monetary policy shocks

Figure 2 depicts the pattern of responses of the main variables to a common monetary policy shock. The calibrated shock generates an unexpected rise of the nominal interest rate of 38 basis points, which is similar to the results obtained in recent VAR literature for the Euro area (see Peersman and Smets, 2001). The two lines represent the impulse responses for the case of symmetric economies with equal demand elasticities consistent with a 10 per cent steady state markup (solid line) and for the asymmetric case in which the domestic economy has higher market competition than the foreign one (benchmark case: dashed line). In all cases, the presence of price stickiness leads to a temporary fall in output followed by a gradual recovery to the baseline level that takes about a year and a half. The response of output in both countries is similar. The response of prices is

[15] Duarte and Wolman (2002) also discuss the volatility of the inflation differentials within the EMU under asymmetric fiscal and productivity shocks.

different, though, in the case of different demand elasticities: because of lower price elasticity in the less competitive (foreign) economy, the price set by the producers of both domestic goods (P_H^*) and of foreign goods (P_F^*) sold in that economy responds less to marginal costs. Hence, foreign inflation falls less than the domestic one. The negative inflation differential ($\pi - \pi^*$) of 28 basis points is substantial but it vanishes rather quickly.[16] When the simulation of the monetary policy shock is done with the more standard Taylor rule parameters (i.e. we add a response to the output gap in both countries of 0.5 in equation (2.8)) we generate a slightly lower fall in output and inflation in both countries but the inflation differential is very similar. Obviously, no inflation differential is generated in the symmetric case.

Both, the inflation differential as well as the implied inflation dispersion (measured by the standard deviation) statistics are also reported in Table 3. In the benchmark case, this common shock generates an standard deviation of 0.20 percent whereas the actual standard deviation of the HICP is 1 percent (Figure 1).[17] Therefore these differences in the degree of competition may explain up to one fourth of the actual inflation dispersion.

Figure 3A shows the size of this impact inflation differential for alternative values of the foreign demand elasticity (while keeping domestic markup at the 10 per cent benchmark value). The starting point is the symmetric case, where the relative demand elasticity is 1. As expected, the difference in the response of the two national inflation rates to the common shock becomes larger as the less competitive country becomes lesser so (with smaller demand elasticity θ^*) since this leads to an even milder response of the two components of the foreign country consumer price index. As the relative elasticity $\frac{\theta}{\theta^*}$ increases, corresponding to an increase in the foreign country markup from 10 to 30 per cent, the steady-state price level differential rises from 4.5 to 18 per cent. As the heterogeneity across

[16] Note that there is no attempt in the model to account for realistic inflation inertia. The persistence of such differential could be increased by e.g. introducing explicitly a lagged inflation term in the Phillips curve in the spirit of the hybrid new Keynesian Phillips curves.

[17] That number would be 0.8 if we were considering just the industrial goods without energy in the four biggest euro area economies, so that the model experiment is more comparable.

economies gets larger, so does the impact inflation differential that goes up to 70 basis points, in response to the aggregate shock. The persistence of such inflation differential increases also as the difference in the degree of market competition across countries increases, but to a far lesser extent.

Table 3

Sensitivity Analysis Under Alternative Shocks: Impact responses

	Monetary		Asym. Demand		Asym. Supply	
	π Diff	$std(\pi, \pi^*)$	π Diff	$std(\pi, \pi^*)$	π Diff	$std(\pi, \pi^*)$
Symmetric [(1)]	0	0	−0.42	0.29	−0.11	0.07
Benchmark [(2)]	−0.28	0.20	−0.16	0.12	−0.07	0.05
Sensitivity						
Competition:						
$\theta < \theta^*$ [(3)]	2.30	1.63	−2.07	1.46	−0.32	0.23
$\theta > \theta^*$ [(4)]	−0.70	0.50	0.24	0.16	−0.01	0.01
Price Inertia:						
$\phi^* = 70.5$	−0.25	0.18	−0.21	0.15	−0.16	0.31
$\phi^* = 167$	−0.33	0.23	−0.11	0.07	−0.01	0.01
Substitution:						
Lower ($\varepsilon \simeq 1$)	−0.28	0.20	−0.26	0.18	−0.10	0.07
Higher ($\varepsilon = 4$)	−0.29	0.21	0.03	0.02	−0.02	0.01
Openness:						
High $\frac{\omega_F}{\omega_H}$=1	−0.30	0.21	0.18	0.13	−0.01	0.01

(1) $\theta = \theta^* = 11$, ϕ, ϕ^*=100, ε=1.5, $\frac{\omega_F}{\omega_H} = \frac{\omega_H^*}{\omega_F^*}$=0.48, $\overline{\frac{P^*}{P}} \frac{\overline{c}^*}{\overline{c}}$=1

(2) As in (1) except for $\theta = 11 > \theta^* = 7.6$

(3) As in (2) except for $\theta = 11 < \theta^* = 91.9$

(4) As in (2) except for $\theta = 11 > \theta^* = 4.3$

Differential inflation responses are also affected by the degree of price rigidity faced by each producer. To quantify his effect we have kept the domestic price inertia at the benchmark value, i.e. $\phi = 100$, while allowing the less competitive foreign economy to vary from very low to fairly high price inertia (ϕ^* from 50 to 200) as shown in Figure 3B. Higher price inertia in the more competitive domestic economy reduces the impact response of prices relative to that in the other country, thus generating smaller negative inflation differentials, while the opposite is true to the right of the benchmark value of $\frac{\phi^*}{\phi} = 1$, where the less competitive foreign economy is also the more sticky. Figure 3B also shows that inflation differentials induced by common shocks are much less sensitive to variations in relative price inertia than they are to variations in the relative degree of competition.

We now look at a specific business cycle feature of the EMU and analyze how the model can reproduce it. Once we consider a monetary union and leave fixed the nominal exchange rate, the volatility of the relative prices becomes a relevant business cycle statistic. Table 4 shows the volatility of the cyclical component of the relative price observed for different EMU countries with respect to Germany.[18] We find that the relative price volatility is lower than the volatility of output (except in Italy). The average value of the ratio between these two magnitudes for the reported EMU countries is 0.62, but reaches 0.75 for the average of the main EMU economies (Spain, Germany, Italy and France). In a similar work, Chari, Kehoe and McGrattan (2001) report a much larger real exchange rate volatility of US with respect to Europe (4.5 times the volatility of US GDP for the period 1973-2000), that is mostly caused by nominal exchange rate fluctuations in the period. We acknowledge that during the nineties, although the Euro area countries belonged to the EMS, the exchange rate policies and the independent monetary policies may have affected those numbers, and therefore they are not fully comparable to the ones predicted by the model

[18] The cyclical components have been obtained applying the Baxter-King filter to the logs of the original series. The source of the data is the Quarterly National Accounts from Eurostat. All variables are converted into Euro equivalents. The maximum sample period available for Germany, and hence for the comparisons with that country is 1991q1-2001q4. Ireland has been excluded due to lack of data. Prices are measured by the GDP deflator.

Table 4

Business cycle fluctuations			
Euro area (1991-2001)			
	$std(y)$	$std(P/P^{\mathrm{GE}})$	$\frac{std(P/P^{\mathrm{GE}})}{std(y)}$
Belgium	1.07%	0.39%	0.36
Germany	0.69%	0	0
Greece	0.93%	0.66%	0.56
Spain	1.04%	0.60%	0.57
France	0.76%	0.45%	0.43
Italy	0.79%	0.99%	1.26
Netherlands	0.84%	0.57%	0.67
Austria	0.77%	0.48%	0.63
Finland	1.96%	1.08%	0.55

The value of $\frac{std(P/P^*)}{std(y^*)}$ generated by the model for the benchmark parameterization when the common monetary policy shocks are the only source of fluctuations is 0.73, close to the one observed for the average big Euro area country in the last decade. Figure 4 shows how the volatility of relative prices after a common shock changes as we change the degree of competition in the foreign economy. As expected, the more different the demand elasticities in the two countries the more volatile the relative prices. As discussed earlier, lower competition makes foreign producer prices less sensitive to a contractionary monetary policy shock, thus increasing the difference between the price responses in the two countries. In fact, when both countries are equally competitive, the relative prices do not change after the common shock.

Figure 4 also shows that the sensitivity to the relative demad elasticity across countries is smaller the higher the level of price inertia. For degrees of price inertia that are common across EMU countries, the picture resembles very much the benchmark case (solid line), and significant discrepancies only arise for very large differences in the degree of market competition. Allowing for more flexible prices in the foreign country like the estimated for The Netherlands ($\phi^* = 70.5$) increases the differences in price reactions and therefore causes a higher volatility of relative prices after a common shock. The opposite occurs when one of the countries has more price inertia like the estimated for Spain ($\phi^* = 167$), but it can be seen that in this latter case, the sensitivity of the relative prices volatility to the markup differential is smaller. This is even more clearly seen when one of the countries has a very high price inertia such as the one estimated for Italy ($\phi^* = 10000$). The volatility of relative prices becomes substantially different and very insensitive to differences in the degree of competition.

In sum, small differences in the price elasticity of demand across countries are sufficient to generate the amount of cross-country relative price volatility observed in the data even for shocks that are common to both countries.[19] Consistently with what we found in the inflation differential impulse responses, the sensitivity of relative price fluctuations to a reasonable range of different price stickiness across countries is smaller than to a moderate range of demand elasticities ratios.

These results are sensitive to some parameters of the model, especially the labor supply elasticity, that is measured with a high degree of uncertainty. We have experimented with a value of $1/\chi = 1$, more according with macro calibrations, and obtained that the model generates lower real marginal cost volatility and therefore lower variability of output and prices in both economies. In particular, for this parameterization the inflation differential becomes -0.16 and the relative price volatility 0.41. Thus, under this alternative parameterization we explain a slightly lower proportion of the observed traded goods inflation variability in the Euro area.

4.2. Asymmetric real demand and supply shocks

Figure 5 depicts the impulse responses, under the benchmark calibration, to a positive demand shock originated in the less competitive (foreign) economy that generates a negative inflation differential of 16 basis points on impact. The shock to real demand in the foreign country affects positively domestic inflation: on the one hand imported goods prices are higher and on the other foreign demand rises

[19] An even smaller difference would be sufficient to match the relative price volatility if we were trying to match the volatility of the relative consumption deflator (0.48 times consumption volatility on average for the main EMU economies) rather than that of the GDP deflator.

as well. The monetary policy rule reacts to this rise in inflation by increasing nominal interest rates, making most of the effects of the positive shock disappear after two years.

The relative inflation response also varies with the differences in market competition across countries, as shown in Table 3. As competition increases in the foreign economy, prices in that economy react more on impact after the demand shock and therefore the negative inflation differential gets higher (-2.07). On the contrary, as the markup in the foreign economy increases (up to 30 per cent) due to a lower demand elasticity, its inflation response becomes smaller, thus reverting the inflation differential generated on impact (0.24). The table also shows the sensitivity of this impact response to changes in the degree of price stickiness. The variation in the inflation differential is now more pronounced than it was in the case of the symmetric shock. The higher the price inertia in the country suffering the shock the smaller the reaction of its prices and hence the smaller the inflation differential observed.

Figure 6 depicts the impulse responses under the benchmark parameterization to an unanticipated negative technology shock in the less competitive foreign country. In this case the negative foreign supply shock affects positively domestic inflation through higher import prices, but it lowers foreign demand of domestic goods which contributes negatively to home inflation $\hat{\pi}_t$. The overall effect is a small rise on domestic inflation. Domestic inflation rises less than foreign inflation yielding a negative inflation differential, that is also sensitive to the relative degree of competition and to relative price inertia. Table 3 shows that the less competitive the country suffering the shock (lower price elasticity θ^*) and the higher its price inertia, the lower the inflation reaction in that country and thus the lower the inflation differential generated as a consequence of the shock.

4.3. Sensitivity to the degree of substitution and of openness

Price dynamics are also affected by the elasticity of substitution between domestic and foreign goods ($\varepsilon = \frac{1}{1-\rho}$) as well as by the degree of openness ($\frac{\omega_F}{\omega_H}$). The effect of changes in that elasticity depends on the nature of the shocks. In the case of a common shock, like a monetary policy shock, the effect of a change in the elasticity of substitution is insignificant. But in presence of a regional shock, the higher the elasticity of substitution, the lower the relative inflation differential. Quantitatively, this is a very relevant parameter: as shown in Table 3, a change in the elasticity of substitution, from 1 to 4, makes the inflation differential generated on impact almost to vanish by an asymmetric demand or supply shock.

Our previous results correspond to a calibration representing two EMU countries that are equally open. In the benchmark model, the ratio of foreign to home goods in consumption $\frac{\omega_F}{\omega_H}$ is calibrated to 0.48 which represents a 25 per cent of imports in the aggregate consumption bundle and corresponds to the average value observed during the nineties for the main Euro area countries. But there are a number of other countries with a significantly higher share of imports. Our model can be modified to analyze the implications of cross country differences in the degree of openness (or home bias in consumption). To that end we parametrize the more competitive domestic economy also as the more open onewith ratios similar to those of The Netherlands (see Table 2), $\frac{\omega_F}{\omega_H} = 1$ and $\frac{\bar{c}_H}{\bar{y}} = 0.50$, corresponding to a 50 per cent of imported goods, whereas the less competitive foreign economy keeps the benchmark parameterization and becomes the less open.[20]

Table 3 summarizes the effect that changes in openness have on the impact inflation differential. This impact response is not significantly altered under an unexpected rise in nominal interest rates. This is not surprising since symmetric shocks affect both $\widehat{d}_t$ and $\widehat{d}_t^*$ in a similar way and hence their effect on the inflation rates is roughly independent on the value of $\frac{\omega_F}{\omega_H}$. Nevertheless, we do find significant changes in presence of regional demand or supply shocks. Under an asymmetric demand shock the inflation differential goes from -16 to 18 basis points. The explanation hinges on the fact that as the economy becomes more open output and inflation respond more to foreign shocks. To the extent that domestic inflation may rise more than that of the country suffering the shock, a

[20] The relative size of the two countries is modified accordingly, so that the balance of payments equilibrium is satisfied.

positive impact inflation differential can be generated.

Similarly, in presence of a negative supply shock in the foreign economy the transmission to the domestic country is more significant the more open is that economy. Now the weight of import prices is higher than in the benchmark case, causing a bigger rise in domestic inflation. Domestic inflation responds almost twice as much and therefore produces a very low inflation differential.

5. Concluding remarks

What explains temporary inflation differentials in monetary unions? This paper goes half of the way to answer this question. In particular we focus on the determinants of those inflation differentials that are not associated with long run processes of productivity catching-up and/or price level convergence. Even within long existing monetary unions there is a significant amount of price variability across countries at business cycle frequencies. Part of the explanation relies on asymmetric or regional shocks. But even shocks of this kind cannot reproduce the observed dispersion of inflation rates unless we assume that countries within the union differ in some crucial features that govern the way markets adjust. These differences may also account for inflation differentials in response to symmetric shocks, like the innovations to the common monetary policy instrument.

This paper parameterizes a two-country monetary union in which different economic structures in the two countries generate permanent price level differences and temporary inflation differentials. These structural asymmetries consist on cross-country heterogeneity in the degree of competition in the goods markets, which cause producers to discriminate prices, different price inertia and different degrees of openness or preference for foreign goods in consumption. Once we allow for moderate cross-country variations in the degree of nominal and real rigidities, we are able to generate sizeable inflation differentials in a model calibrated to match the most salient long run features of the average big EMU economies.

In presence of common shocks, the relative degree of market competition turns out to be a crucial parameter governing the relative price responses. Small deviations on the degree of competition that account for 5 per cent long run price level difference across countries may be responsible for temporary inflation differentials of up to 28 basis points when the economy is subject to a common monetary policy shock. Small differences in the degree of nominal inertia also contribute to generate substantial inflation differentials, although the relevance of this channel is quantitatively less important. Not surprisingly, in presence of regional (asymmetric) shocks, also the elasticity of substitution between home produced and imported goods and the degree of openness play a major role to produce realistic values of the main statistics of interest.

We have focused on short-term measures of inflation like impact responses or countries' dispersion of these responses. But these inflation differentials could last longer.They can be generated not only by ad-hoc persistent sources of fluctuations or ad-hoc inflation inertia, but also by endogenous mechanisms like the consideration of capital accumulation or the existence of real frictions (e.g. habit formation or investment adjustment costs). Moreover, the differences in countries' competitiveness and the degree of openness may be completed with other structural differences (e.g. taxation or labour costs) that are known to be relevant in the context of the EMU. We leave the interaction of these elements for further research.

Appendix

The equilibrium (in log-linear form) is represented by the following system of 23 equations and 23 endogenous variables: $\widehat{c}_t$, $\widehat{c}_{H,t}$, $\widehat{c}_{F,t}$, $\widehat{c}^*_t$, $\widehat{c}^*_{F,t}$, $\widehat{c}^*_{H,t}$, $\widehat{P}_t$, $\widehat{P}_{H,t}$, $\widehat{P}_{F,t}$, $\widehat{P}_t$, $\widehat{P}^*_{H,t}$, $\widehat{P}^*_{F,t}$, $\widehat{y}_t$, $\widehat{y}_{H,t}$, $\widehat{y}^*_{H,t}$, $\widehat{y}^*_t$, $\widehat{y}^*_{F,t}$, $\widehat{y}_{F,t}$, a_t, a^*_t, $\widehat{r}_t$, $\widehat{\pi}_t$, $\widehat{\pi}^*_t$.

$$\widehat{P}_{F,t} - \widehat{P}_{H,t} = (1-\rho)\left(\widehat{c}_{H,t} - \widehat{c}_{F,t}\right) \tag{A1}$$

$$\widehat{c}_t = E_t\widehat{c}_{t+1} - \frac{1}{\sigma}\left(\widehat{r}_t - E_t\widehat{\pi}_{t+1} - \left(\frac{\psi}{\overline{r}}\right)a_t\right) + \frac{1}{\sigma}\left(\widehat{s}_t - E_t\widehat{s}_{t+1}\right) \tag{A2}$$

$$\begin{aligned}\widehat{P}_{H,t} = {} & \frac{1}{1+\beta}\widehat{P}_{H,t-1} + \frac{\beta}{1+\beta}E_t\widehat{P}_{H,t+1} \\ & + \frac{\mu_H}{1+\beta}\left[(\alpha-1)\widehat{y}_t - (1-\sigma)\widehat{c}_t + \widehat{c}_{H,t} + \alpha\widehat{v}_t\right]\end{aligned} \tag{A3}$$

$$\begin{aligned}\widehat{P}^*_{H,t} = {} & \frac{1}{1+\beta+\mu^*_H}\widehat{P}^*_{H,t-1} + \frac{\beta}{1+\beta+\mu^*_H}E_t\widehat{P}^*_{H,t+1} + \frac{\mu^*_H}{1+\beta+\mu^*_H}\widehat{P}_{H,t} \\ & + \frac{\mu^*_H}{1+\beta+\mu^*_H}\left[(\alpha-1)\widehat{y}_t - (1-\sigma)\widehat{c}_t + \widehat{c}_{H,t} + \alpha\widehat{v}_t + (\widehat{P}_{Ht} - \widehat{P}^*_{Ht}\right]\end{aligned} \tag{A4}$$

$$\widehat{c}_t = \omega_H\left(\frac{\overline{c}_H}{\overline{c}}\right)^{\rho}\left(\widehat{c}_{H,t}\right) + \omega_F\left(\frac{\overline{c}_F}{\overline{c}}\right)^{\rho}\left(\widehat{c}_{F,t}\right) \tag{A5}$$

$$\widehat{y}_t = \left(\frac{\overline{y}_H}{\overline{y}}\right)\widehat{y}_{H,t} + \left(\frac{\overline{y}^*_H}{\overline{y}}\right)\widehat{y}^*_{H,t} \tag{A6}$$

$$\widehat{P}_t = (\omega_H)^{\left(\frac{1}{1-\rho}\right)}\left(\frac{\overline{P_H}}{P}\right)^{\left(\frac{\rho}{\rho-1}\right)}\left(\widehat{P}_{H,t}\right) + (\omega_F)^{\left(\frac{1}{1-\rho}\right)}\left(\frac{\overline{P_F}}{P}\right)^{\left(\frac{\rho}{\rho-1}\right)}\left(\widehat{P}_{F,t}\right) \tag{A7}$$

$$\widehat{\pi}_t = \widehat{P}_t - \widehat{P}_{t-1} \tag{A8}$$

$$\beta \left(\frac{\overline{P_H^*}}{P}\right) \frac{\overline{c}_H^*}{\overline{c}} (\widehat{P}_{H,t}^* + \widehat{c}_{H,t}^* - \widehat{P}_{F,t} - \widehat{c}_{F,t}) + a_{t-1} = \beta a_t \tag{A9}$$

$$\widehat{P}_{F,t}^* - \widehat{P}_{H,t}^* = (1-\rho) \left(\widehat{c}_{H,t}^* - \widehat{c}_{F,t}^*\right) \tag{A10}$$

$$\widehat{c}_t^* = E_t \widehat{c}_{t+1}^* - \frac{1}{\sigma} \left(\widehat{r}_t - \widehat{\pi}_{t+1}^* - \left(\frac{\psi}{\overline{r}}\right) a_t^*\right) + \frac{1}{\sigma} \left(\widehat{s}_t^* - E_t \widehat{s}_{t+1}^*\right) \tag{A11}$$

$$\begin{aligned} \widehat{P}_{F,t}^* &= \frac{1}{1+\beta} \widehat{P}_{F,t-1}^* + \frac{\beta}{1+\beta} E_t \widehat{P}_{F,t+1}^* \\ &+ \frac{\mu_F^*}{1+\beta} \left[(\alpha-1)\widehat{y}_t^* - (1-\sigma)\widehat{c}_t^* + \widehat{c}_{F,t}^* + \alpha \widehat{v}_t^*\right] \end{aligned} \tag{A12}$$

$$\begin{aligned} \widehat{P}_{F,t} &= \frac{1}{1+\beta+\mu_F} \widehat{P}_{F,t-1} + \frac{\beta}{1+\beta+\mu_F} E_t \widehat{P}_{F,t+1} + \frac{\mu_F}{1+\beta+\mu_F} \widehat{P}_{F,t}^* \\ &+ \frac{\mu_F}{1+\beta+\mu_F} \left[(\alpha-1)\widehat{y}_t^* - (1-\sigma)\widehat{c}_t^* + \widehat{c}_{F,t}^* + \alpha \widehat{v}_t^* + \left(\widehat{P}_{Ft}^* - \widehat{P}_{Ft}\right)\right] \end{aligned} \tag{A13}$$

$$\widehat{c}_t^* = \omega_H^* \left(\frac{\overline{c}_H^*}{\overline{c}^*}\right)^{\rho} \left(\widehat{c}_{H,t}^*\right) + \omega_F^* \left(\frac{\overline{c}_F^*}{\overline{c}^*}\right)^{\rho} \left(\widehat{c}_{F,t}^*\right) \tag{A14}$$

$$\widehat{y}_t^* = \left(\frac{\overline{y}_F}{\overline{y}^*}\right) \widehat{y}_{F,t} + \left(\frac{\overline{y}_F^*}{\overline{y}^*}\right) \widehat{y}_{F,t}^* \tag{A15}$$

$$\widehat{P}_t^* = (\omega_H^*)^{\left(\frac{1}{1-\rho}\right)} \left(\frac{\overline{P_H^*}}{P^*}\right)^{\left(\frac{\rho}{\rho-1}\right)} \left(\widehat{P}_{H,t}^*\right) + (\omega_F^*)^{\left(\frac{1}{1-\rho}\right)} \left(\frac{\overline{P_F^*}}{P^*}\right)^{\left(\frac{\rho}{\rho-1}\right)} \left(\widehat{P}_{F,t}^*\right) \tag{A16}$$

$$\widehat{\pi}_t^* = \widehat{P}_t^* - \widehat{P}_{t-1}^* \tag{A17}$$

$$a_t^* \left(\frac{\overline{P^*}}{P}\right) \frac{\overline{c}^*}{\overline{c}} + a_t = 0 \tag{A18}$$

$$\widehat{c}_{H,t} = \widehat{y}_{H,t} \tag{A19}$$

$$\widehat{c}^{*}_{H,t} = \widehat{y}^{*}_{H,t} \tag{A20}$$

$$\widehat{c}_{F,t} = \widehat{y}_{F,t} \tag{A21}$$

$$\widehat{c}^{*}_{F,t} = \widehat{y}^{*}_{F,t} \tag{A22}$$

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1-\rho_r)\rho_\pi \frac{1}{2}(\widehat{\pi}_t + \widehat{\pi}^{*}_t) + z_{r,t} \tag{A23}$$

where $\mu_H = \frac{(\theta-1)}{\phi\bar{\pi}^2}$; $\mu^{*}_H = \frac{(\theta^{*}-1)}{\phi\bar{\pi}^2}$; $\mu^{*}_F = \frac{(\theta^{*}-1)}{\phi^{*}\bar{\pi}^2}$; $\mu_F = \frac{(\theta-1)}{\phi^{*}\bar{\pi}^2}$.

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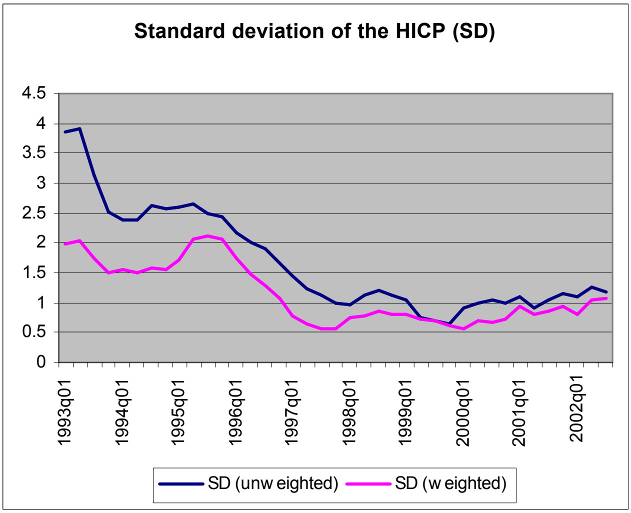
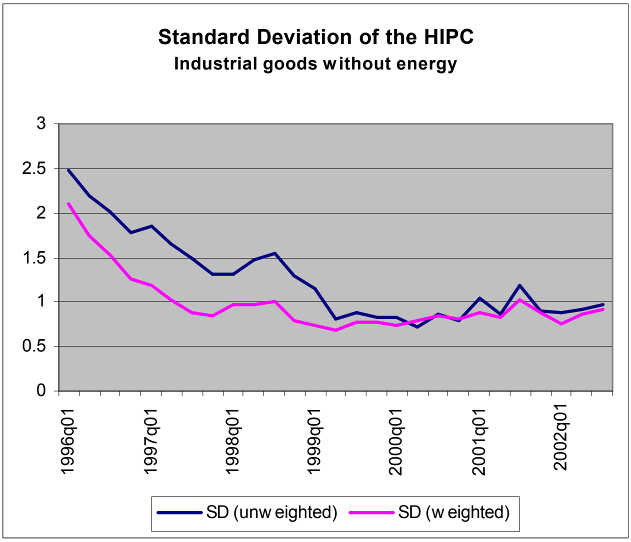
FIGURE 1

MEASURES OF HICP INFLATION DISPERSION ACROSS EURO AREA COUNTRIES

Panel A



Panel B



Note: Standard deviation of annual rates of inflation in percentage points. The weights for each country are the share of the constant GDP at market prices (PPP) for 1995.

FIGURE 2

RESPONSES TO A CONTRACTIONARY MONETARY POLICY SHOCK

Symmetric case (solid line), benchmark (dashed line)

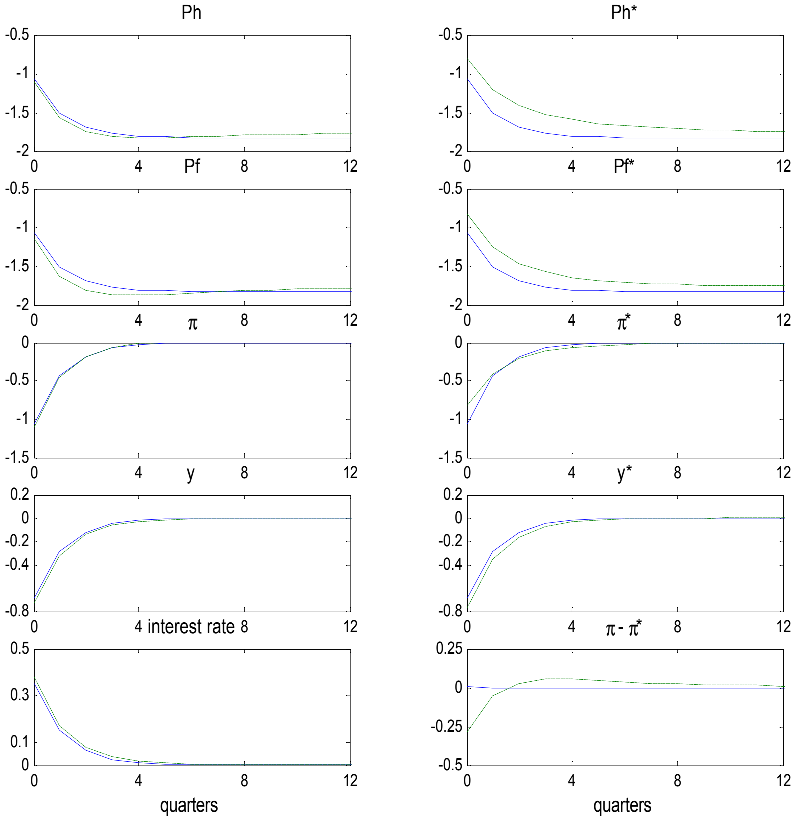
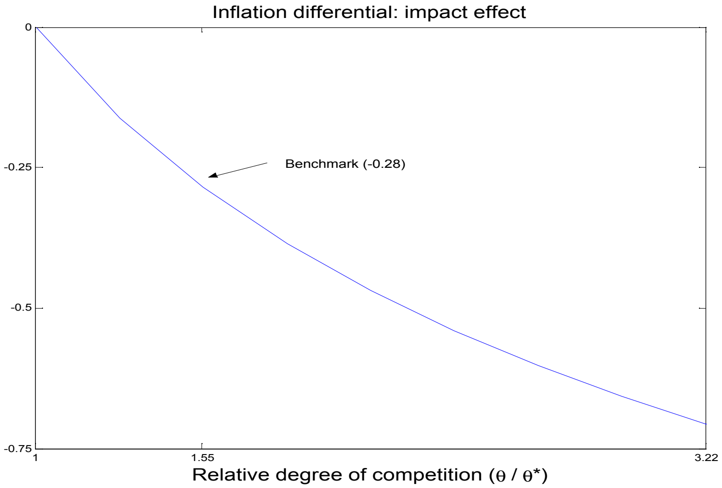


FIGURE 3

INFLATION DIFFERENTIAL
IMPACT EFFECT UNDER A CONTRACTIONARY MONETARY POLICY SHOCK

Panel A



Panel B

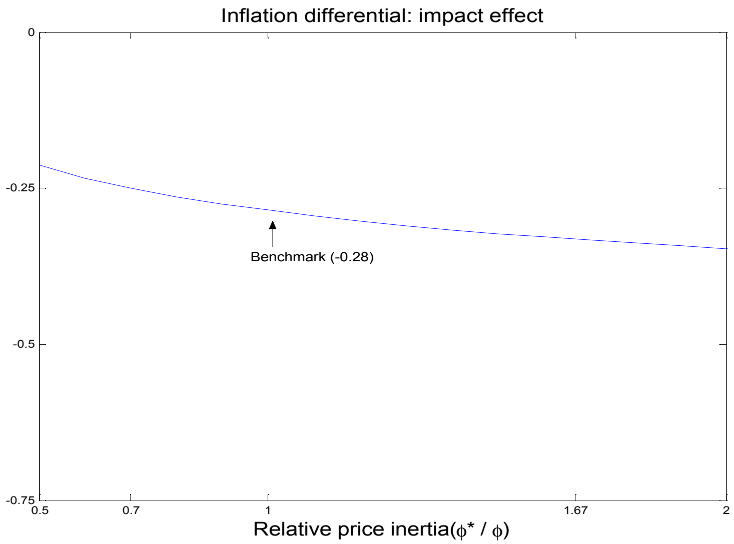


FIGURE 4

VOLATILITY OF RELATIVE PRICES
UNDER A CONTRACTIONARY MONETARY POLICY SHOCK

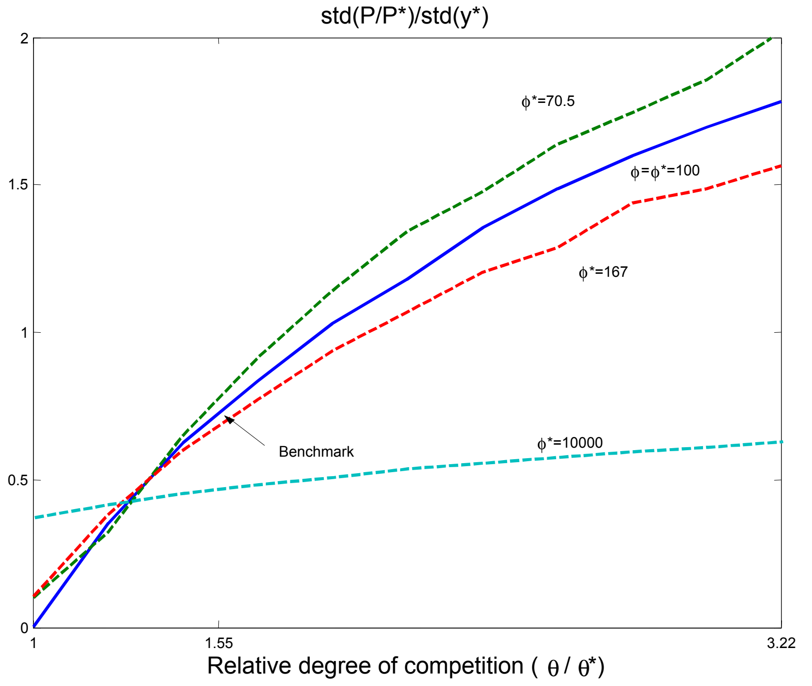


FIGURE 5

RESPONSES TO AN ASYMMETRIC POSITIVE DEMAND SHOCK (F COUNTRY)

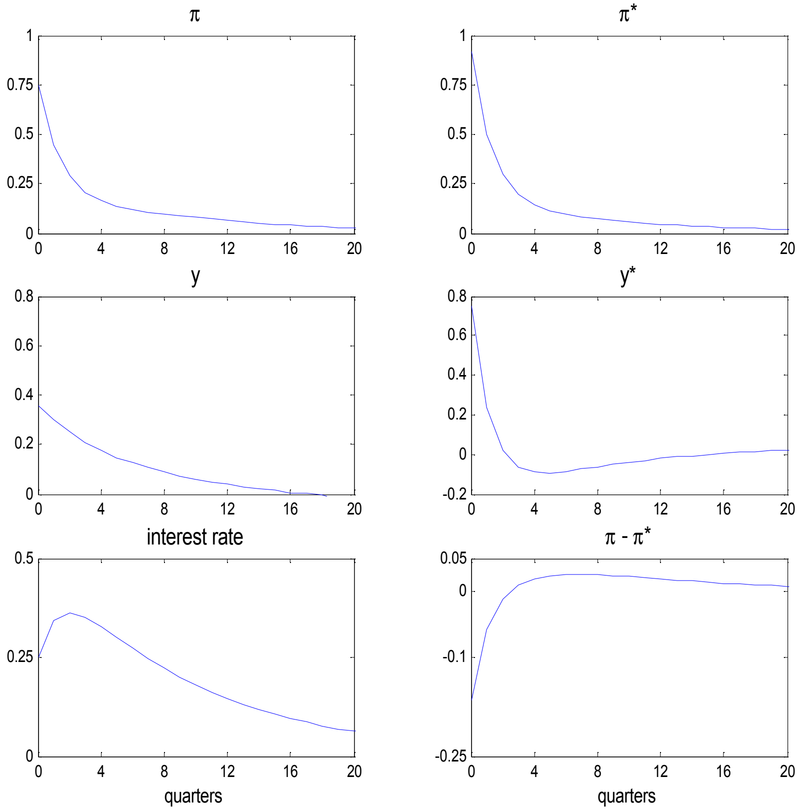


FIGURE 6

RESPONSES TO AN ASYMMETRIC NEGATIVE SUPPLY SHOCK (F COUNTRY)