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World Food Prices, the Terms of Trade-Real Exchange Rate Nexus, and Monetary Policy

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World Food Prices, the Terms of Trade-Real Exchange Rate Nexus, and Monetary Policy[1]

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Abstract

How should monetary policy respond to large fluctuations in world food prices? We study this question in an open economy model in which imported food has a larger weight in domestic consumption than abroad and international risk sharing can be imperfect. A key novelty is that the real exchange rate and the terms of trade can move in opposite directions in response to world food price shocks. This exacerbates the policy trade-off between stabilizing output prices vis a vis the real exchange rate, to an extent that depends on risk sharing and the price elasticity of exports. Under perfect risk sharing, targeting the headline CPI welfare-dominates targeting the PPI if the variance of food price shocks is not too small and the export price elasticity is realistically high. In such a case, however, targeting forecast CPI is a superior choice. With incomplete risk sharing, PPI targeting is clearly a winner.

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1. Introduction

While much has been written on the inflationary impact of oil price shocks and its implications for monetary policy[1], little attention has been given to the role of food price shocks. At a global level, Figure 1 indicates that this omission is unwarranted. Plotting the IMF global food price index against standard proxies for global tradable goods prices, Figure 1 shows not only that the correlation is sizeable (around 0.6) but also that food prices often lead rather than lag global inflation. This is corroborated by formal causality tests: changes in food prices tend to Granger-cause global inflation even after controlling for oil price changes.[2] This evidence may not come as a surprise, since food typically weighs heavily in consumption baskets and is not easily substitutable; yet, it does call for careful analyses of the implications of price shocks for monetary policy.

The key question is the extent to which monetary policy should accommodate such shocks. If food is mostly imported, rules that target inflation measured by the overall consumer price index (CPI) prescribe a more aggressive reaction to imported inflation than rules targeting a producer price index (PPI) or a wholesale price index (WPI). Since gyrations in imported food inflation can be large, different rules entail very different policy responses and macroeconomic outcomes. This was clearly illustrated recently by looser monetary stances during the food price surge of 2005-07 which led to significant breaches of upper tolerance bands in several inflation targeting regimes (Catão and Chang, 2011).

While the monetary policy literature has not previously modeled the effects of food price shocks explicitly, closed economy models generally prescribe that monetary policy should target the PPI or related indices such as "core" CPI (see, e.g., Goodfriend and King, 2001; Aoki, 2001; Woodford, 2003; and Walsh, 2004). Further, in the absence of supply shocks, these models also imply that PPI stabilization is conducive to output stabilization – the so-called "divine co-

[1]See e.g. Blanchard and Gali (2005, 2007), Bodenstein, Erceg and Guerrieri (2008), Kilian (2009), IMF (2011) and the various references therein.

[2]This readily follows from regressing either the US WPI or the (GDP weighed) world WPI on changes in the log of the IMF price indices of global food and of oil commodities over the period 1970-2011. The F-statistic on the exclusion of the food inflation index from the US WPI regression is significant at 5% level; if the world CPI index is used, the statistical significance is higher than 1%. These inferences are robust to whether one uses HP-filter detrended indices instead of changes in the log indices. Data and specifics of estimation are available from the authors upon request.

incidence".[3] In open economies, the policy analysis has been shown to be subtler due to imperfect competition in international goods markets, incomplete world financial integration, liability dollarization, and pricing to market.[4] Such open economy features imply a new menu of trade-offs that can potentially overturn the prescriptions of the closed economy literature. Still, the thrust of the open economy literature has been that PPI targeting remains best for welfare except in particular cases – notably, when the intratemporal elasticity of substitution in consumption is sufficiently high, in which case either headline CPI targeting or nominal exchange rate pegging deliver superior welfare.[5]

Previous studies largely assume international risk sharing to be perfect.[6] From a different vantage point, and focusing on the case of commodity exporters, Frankel (2010, 2011) has argued that capital market imperfections gives PPI targeting, if anything, a further edge over CPI targeting because the latter tends to exacerbate output procyclicality. His argument is that a fall in the world relative price of exports translates into a terms of trade deterioration and a nominal exchange rate depreciation which raises CPI inflation on impact. Under CPI targeting, this calls for monetary tightening, thus reinforcing the contractionary effect of the terms of trade deterioration on domestic output. Since limited international risk sharing limits consumption smoothing, consumption will fall in tandem with output, lowering welfare.

Against that background, it is surprising to note that broad CPI has been the index explicitly targeted by most central banks, including those in many commodity exporting countries.[7] This further underscores the need for a reassessment of the prevailing wisdom.

[3] The literature acknowledges that the "divine coincidence" breaks down under real wage rigidities. But the prescribed second-best in this case is to suitably weigh the output gap in the Taylor rule so as to minimize the inflation-employment trade-off at the cost of higher CPI inflation (Blanchard and Gali 2005, 2009).

[4] See, in particular, Corsetti and Pesenti (2001), Kollman (2002), Devereux and Engel, (2003), Benigno and Benigno (2003), Céspedes et al. (2004), Gali and Monacelli (2005), Sutherland (2005), Bergin et al. (2007), Monacelli and Faia (2008).

[5] This is due to their stabilizing effects on the real exchange rate (Cova and Sondergaard, 2004; de Paoli, 2009).

[6] The notable exceptions are Kollman (2002) and Bergin et al (2007) whose models feature a non-state contigent foreign bond. Yet, as it turns out, they also prescribe targeting PPI .

[7] See de Gregorio (2012) for detailed documentation of central banks' targeting rules and their evolution over the last decade. He shows that the closest variant of PPI targeting adopted in practice (that of targeting "core" CPI, i.e., purging the latter from commodity items such as oil and food) is only adopted by a minority of central banks.

In this paper, we focus on a setting that is realistic for many economies – namely, a model of a country where importable food commodities weigh heavily in the domestic consumption basket and that enjoys less than complete international risk sharing. From an analytical standpoint, our setting is of particular interest since it corresponds to the "worst sufferer" from rising world food inflation: being a net food importer, its terms of trade must deteriorate, while a large share of food in the domestic consumption basket translates into high CPI inflation; also, with food shares higher at home than abroad, the real exchange rate appreciates on impact to the extent that domestic inflation is higher than foreign inflation.

To study which monetary rule can be most effective in this context, we extend the canonical open economy setting of Gali and Monacelli (2005) in several ways. An obvious but key modification is to let "food" be a distinct commodity that enters the home consumption basket with possibly very low substitution elasticity *vis a vis* other goods, and that is traded in competitive, flexible price markets.[8] Other extensions include: (1) global food prices can vary widely relative to the overall world price index; (2) food expenditure shares at home and the rest of the world can differ significantly; (3) the export price elasticity of the world demand for home exports can differ from the intratemporal elasticity of substitution home and imported goods in consumption; (4) international risk sharing can be incomplete.[9]

The resulting setting allows us to capture a important (and much overlooked) empirical regularity in many emerging and developing countries: in response to a shock to the world relative price of food, the terms of trade and the real exchange rate can move in opposite directions. This response patters stems from food having a higher weight in the domestic consumption basket than in the foreign one and from the country being a net food importer. Higher world food prices then increase the overall cost of consumption at home relative to that abroad (a real appreciation) while weakening the relative price of domestic exports (a fall in

[8] For evidence that food production is a more competitive industry than most others, displaying fast pass-through from cost shocks to prices, as well as high price volatility, see Gouveia (2007).

[9] That (1) is a realistic departure is clear from Figure 1. As for (2), Table 3 provides cross-country evidence: in emerging economies, food consumption is a larger share of expenditure than in more advanced peers. Regarding (3), Slutsky own-price elasticity estimates indicate that food commodities display limited substitutability with non-food goods; in the canonical model as well as ours, such non-food goods are the ones that the country produces for its own consumption as well as exports. Anand and Prasad (2010) provide estimates of the price elasticity of food demand in the 0.1-0.5 range which is well-below the normal 4 to 6 range typically underlying the Dixit-Stiglitz aggregator. As for (4), there is ample evidence that international risk sharing is typically less than full, especially among emerging markets (e.g. Kose et al. 2009).

the terms of trade). As a result, our model easily delivers a negative covariance between the real exchange rate and the terms of trade. This is notable because previous models do not allow for such a negative covariance, which can be a serious shortcoming: Figure 2 illustrates how conspicuous this negative covariance can be in economies which are net food importers and that export mainly sticky price, higher elasticity goods such as manufacturing and/or service goods. As we discuss below, this distinct pattern of comovements between key relative prices poses novel monetary policy trade-offs that can affect policy analysis drastically.

The other major departure from the canonical model is the way we allow for different degrees of international risk sharing. Following Schulhofer-Wohl (2011), we assume the existence of complete financial markets but introduce a costly wedge in the transferring resources out into and out of domestic households. The result is that at any point in time domestic consumption is a convex combination of the polar cases of full risk sharing and portfolio autarky. This specification has the advantage of being both parsimonious and intuitive, while also enabling us to rely on existing estimates for the wedge parameter in our model calibrations.

We provide an analytical discussion of the policy problem which, in particular, yields a complete characterization of Ramsey allocations and flexible price allocations, which are quite informative to interpret the implications of the different policy rules. Finally, in a calibrated version of the model, we obtain numerical comparisons of the relative welfare performance of those rules.

The main results of our numerical exercises are as follows. First, when the variance of imported food price shocks is calibrated to be as large as in the data, international risk sharing is perfect, and the home economy's export price elasticity is not too low, broad CPI targeting delivers higher welfare than PPI targeting. But targeting "expected" or forecast CPI is even superior. The reason is that CPI targeting exploits more heavily the so-called terms of trade externality and better stabilizes the real exchange rate and consumption; in doing so, it delivers a better approximation to the Ramsey allocation than the other rules.

Second, the welfare-superiority of CPI targeting easily vanishes if international risk sharing is less than complete. If the financial transfer cost wedge is positive, PPI dominates other rules for a wide range of parameters.

A third finding is that intratemporal elasticities are critical to welfare rankings of policy rules in a way that was not fleshed out in previous studies. These assumed (with little justification) the price elasticity of home exports and the elasticity of substitution in domestic consumption to be the same. The decoupling of these elasticities (made all the more realistic by the weight of food in CPI) allows us to highlight the crucial role of the export price elasticity, which can tilt the welfare ranking of policy rules.

The remainder of the paper proceeds as follows. Section 2 lays out the model. Section 3 discusses aggregate supply relationships, emphasizing how inflation and the appropriate measure of the output gap are affected by changes in world relative food prices. Section 4 discusses aggregate demand and impulse responses. Section 5 characterizes Ramsey and flex-price market allocations to shed light on the welfare implications of alternative policy rules and the underlying trade-offs. In section 6 we provide numerical results on the welfare ranking of the different policy rules and interpret them in light of the conceptual discussion of the previous section. Section 7 concludes. Some technical derivations are deferred to an Appendix.

2. Model

We study a small open economy populated by identical agents that consume a domestic good and imported food. The domestic good is an aggregate of intermediate varieties produced at home with domestic labor. The model is New Keynesian in that the intermediates sector is characterized by monopolistic competition and nominal rigidities.

We assume that the share of food is larger in the domestic consumption basket than in the world basket, so PPP does not hold. Further, the world price of food in terms of world consumption is exogenous. One consequence is that the real exchange rate appreciates when the world relative price of food rises, and domestic consumption fluctuates with world food prices even under full risk sharing. Also, and in contrast with previous work, our model implies that the terms of trade and the real exchange rate can move in opposite directions.

In another departure from the literature, international risk sharing is allowed to be imperfect. We do this by assuming that domestic households may face costs of transferring resources, as in Schulhofer-Wohl (2011). This leads to a tractable formulation that includes financial autarky and perfect risk sharing as special cases.

2.1. Households

The economy has a representative family or household with preferences:

$$E\sum_{t=0}^{\infty}\beta^{t}\left[\frac{C_t^{1-\sigma}}{(1-\sigma)}-\varsigma\int_0^1\frac{N_t(j)^{1+\varphi}}{1+\varphi}dj\right]$$

where $0<\beta<1$, $E(.)$ is the expectation operator, σ, φ, and ς are parameters, C_t denotes consumption, and $N_t(j)$ is the supply of labor employed by a firm belonging to industry $j\in[0,1]$. As in Woodford (2003), we assume that there is a continuum of industries, each of which employs a different type of labor, and that labor types are not perfect substitutes from the viewpoint of the household.

Consumption is a C.E.S. aggregate of a home final good C_h and an imported good (food) C_f :

$$C_t=\left[(1-\alpha)^{1/\eta}C_{ht}^{(\eta-1)/\eta}+\alpha^{1/\eta}C_{ft}^{(\eta-1)/\eta}\right]^{\eta/(\eta-1)}$$

where η is the elasticity of substitution between home and foreign goods, and α is a measure of the degree of openness.

The price index associated with C, or CPI, expressed in domestic currency, is

$$P_t=\left[(1-\alpha)P_{ht}^{1-\eta}+\alpha P_{ft}^{1-\eta}\right]^{1/(1-\eta)} \tag{1}$$

where P_{ht} and P_{ft} are the domestic currency prices of the home good and imports. Also, given total consumption C_t and prices P_{ht} and P_{ft}, optimal demands for home goods and foreign goods are given by

$$C_{ht}=(1-\alpha)\left(\frac{P_{ht}}{P_t}\right)^{-\eta}C_t \tag{2}$$

$$C_{ft}=\alpha\left(\frac{P_{ft}}{P_t}\right)^{-\eta}C_t$$

If $P_{ht}=P_{ft}$, α equals the fraction of all consumption that is imported. In this sense, α is a measure of openness. [10]

The household owns domestic firms and receives their profits. It chooses consumption and labor effort taking prices and wages as given. With respect to

[10] Home bias corresponds to the case $\alpha<1/2$. We have assumed $\eta\neq 1$. If $\eta=1$, C_t and P_t are Cobb Douglas.

trade in assets, we depart from Gali and Monacelli (2005), di Paoli (2009) and many others in allowing for financial frictions that imply imperfect risk sharing across countries. Specifically, we borrow Schulhofer-Wohl's (2011) closed-economy assumption that the typical household incurs deadweight costs if it transfers resources in or out of the household. Denoting the household's current nonfinancial income by H_t, the assumption is that the household has to pay an extra cost of $\varpi\Phi(C_t, H_t)$ units of consumption, where

$$\Phi(C,H) = \frac{C}{2}\left(\log\left(\frac{C}{H}\right)\right)^2$$

and ϖ is a parameter controlling the severity of this friction.

As shown in the Appendix, this formulation implies that optimal risk sharing is given by the condition

$$C_t^{\sigma}\left[1 + \varpi\Phi_{Ct}\right] = \kappa X_t \left(C_t^*\right)^{\sigma} \tag{3}$$

where κ is a positive constant, C_t^* is an index of world consumption, X_t is the *real exchange rate* (the ratio of the price of world consumption to the domestic CPI, both measured in a common currency), Y_{ht} is domestic output in nominal terms, and $\Phi_{Ct} = \Phi_C(C_t, H_t)$ is the partial derivative of Φ with respect to C evaluated at (C_t, H_t). [11] The intuition is straightforward. If $\varpi = 0$, the preceding expression reduces to the usual perfect international risk sharing condition: marginal utilities of consumption at home and abroad are proportional up a real exchange rate correction. For nonzero ϖ, optimal risk sharing takes into account that each consumption unit transferred to domestic households involves the extra transfer cost $\varpi\Phi_c$, explaining the appearance of this term in the left hand side. Financial autarky corresponds to ϖ going to infinity: in that case, $C_t = H_t = P_{ht}Y_{ht}/P_t$ in equilibrium, so the trade balance is zero in all periods. Schulhofer-Wohl's assumptions thus capture market incompleteness in a way that is attractive in its simplicity, encompassing perfect risk sharing and portfolio autarky as special cases, and (as found below) retaining tractability. [12]

[11] Here we assume that the marginal utility of consumption in the rest of the world is proportional to $C_t^{*-\sigma}$. The assumption that κ is a positive constant and exogenous is standard and implicit assumes that asset trading takes place *before* policy decisions are made. See Sutherland and Szenay (2007) for a discussion of possible implications of the alternative assumption that asset trade takes place after monetary policy decisions.

[12] One might, of course, object that ϖ may be time-varying and, outside the polar cases

Next, if $W_t(j)$ is the domestic wage for labor of type j, optimal labor supply is given by the equality of the marginal disutility of labor with the marginal utility of the real wage, corrected by marginal transfer costs:

$$\varsigma C_t^{\sigma} N(j)_t^{\varphi} = \frac{W_t(j)\left[1 - \varpi \Phi_{Zt}\right]}{P_t\left[1 + \varpi \Phi_{Ct}\right]} \tag{4}$$

Finally, the domestic safe interest rate is given by

$$\begin{aligned} \frac{1}{1+i_t} &= \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t\left(1 + \varpi \Phi_{Ct}\right)}{P_{t+1}\left(1 + \varpi \Phi_{Ct+1}\right)} \right] \\ &\equiv \beta E_t M_{t,t+1} \end{aligned} \tag{5}$$

where we have defined $M_{t,t+j}$ as the period t pricing kernel applicable to nominal payoffs in period $t + j$. This extends in a natural way the familiar expression of the frictionless asset trade case.

2.2. Prices

For simplicity, we assume that all food is imported, and that the world price of food is exogenously given in terms of a world currency. Using asterisks to denote prices denominated in world currency, the domestic currency price of food is then

$$P_{ft} = S_t P_{ft}^{*}$$

where S_t is the nominal exchange rate (domestic currency per unit of foreign currency). So, there is full pass through from world to domestic food prices.

of zero and infinity, ϖ is not readily mapped onto observables. But these objections could be equally raised to the obvious alternative, which is a bond economy. As noted in Schulhofer-Wohl (2011), assuming risk is shared imperfectly via noncontingent bond contracts also amounts to a reduced form specification. In practice, risk sharing takes place through a variety of other financial instruments, both formal and informal, official and private. As shown in Milesi-Ferretti and Lane (2007, 2011), the importance of non-bond instruments has grown so rapidly over the recent decade to the point of dwafting that of fixed income instruments – even among emerging markets.In addition, the new Keynesian model with international bond trading has been already studied by Kollman (2002), Bergin et al. (2007), and others.

Likewise, we assume that the world currency price of the world consumption index is exogenous.[13] Denoting it by P_t^*, the real exchange rate is then:

$$X_t = S_t P_t^* / P_t$$

It is useful also to define the domestic price of food relative to the price of home output, or *terms of trade*, by

$$Q_t = \frac{P_{ft}}{P_{ht}} = \frac{S_t P_{ft}^*}{P_{ht}} \tag{6}$$

As in other models, the terms of trade and the relative price of home output are essentially the same, since 1 implies that

$$\left(\frac{P_t}{P_{ht}}\right)^{1-\eta} = (1-\alpha) + \alpha Q_t^{1-\eta} \tag{7}$$

However, in contrast with other small open economy models, the real exchange rate and the terms of trade are not proportional to each other, reflecting fluctuations in the world price of food relative to the world CPI. To see this, insert the expressions for X_t and P_{ft} into the consumer price index (1) to obtain the following relation between the real exchange rate and the relative price of home final goods:

$$1 = (1-\alpha)\left(\frac{P_{ht}}{P_t}\right)^{1-\eta} + \alpha X_t^{1-\eta} Z_t^{*1-\eta} \tag{8}$$

where $Z_t^* = P_{ft}^*/P_t^*$ is the *world's relative price of food,* which we take as exogenous.

An improvement in the terms of trade (a fall in Q_t) implies an increase in the relative price of domestic output (P_h/P). Given Z_t^*, 8 then implies that X_t must fall (a real appreciation). But X_t and Q_t can move in opposite directions when Z_t^* moves.

Since this aspect of our model is relatively novel, it deserves further elaboration. Other models have typically assumed that home agents consume a domestic

[13] In solving the model, and to simplify the algebra, we make the stronger assumption that shocks to C^* and Z^* are independent. To justify this, one can assume that food has a negligible share in the world consumer basket, in contrast with the domestic basket. This is a defensible assumption since, as shown in Table 3, the share of food in the CPI is substantially higher in small emerging economies than in advanced countries.

aggregate and a foreign aggregate (such as C^* in our model), and that there is some home bias, so that PPP does not hold. In contrast, we assume that home agents do not consume the foreign aggregate but instead a different good (food). This would not make a difference if the relative price of food were fixed in terms of the foreign aggregate (e.g. if $Z^* = 1$). So the basic differences between our model and previous ones emerge because Z^* is allowed to fluctuate.

In particular, the standard specification implies, as can be seen from the three previous expressions, a very tight link between the terms of trade and the real exchange rate: with $Z^* = 1$, X_t and Q_t must *always* move in the same direction. Using lowercase variables for log variables, it turns out that $x_t = (1-\alpha)q_t$ to a first order approximation, so that (to second order) $Var(x_t) = (1-\alpha)^2 Var(q_t)$: the variance of the real exchange rate is proportional to the variance of the terms of trade, the constant of proportionality being less than one and pinned down by the degree of openness. These implications seem quite restrictive.

In our model, in contrast, fluctuations in the relative price of food mean that X_t and Q_t can move in opposite directions (in response of shocks to Z^*). Also, we will see that $x_t = (1-\alpha)q_t - z_t$ to first order, so that the variance of x can be smaller or larger than the variance of q, depending on the volatility of z.

2.3. Domestic Production

Domestic production follows Gali and Monacelli (2005) and others, so we can be brief. The home final good is a Dixit-Stiglitz aggregate of intermediate goods varieties. Cost minimization then implies that the demand for each variety $j \in [0,1]$ is given by

$$Y_t(j) = \left(\frac{P_t(j)}{P_{ht}}\right)^{-\varepsilon} Y_{ht}$$

where ε is the elasticity of substitution between domestic varieties, $P_t(j)$ is the price of variety j, Y_{ht} is the total demand for the home aggregate, and P_{ht} is the relevant price index (the PPI):

$$P_{ht} = \left[\int_0^1 P_t(j)^{1-\varepsilon} dj\right]^{1/(1-\varepsilon)} \quad (9)$$

Each intermediates variety j is produced with only labor of type j according to the production function $Y_t(j) = A_t N_t(j)$, where $N_t(j)$ is the input of type j labor and A_t is a productivity shock, common to all firms in the economy.

Firms take wages as given. We allow for the existence of a subsidy to employment at constant rate υ. Hence nominal marginal cost is given by

$$\Psi_{jt} = (1-\upsilon)W_t(j)/A_t \tag{10}$$

where $W_t(j)$ is the wage rate for type j labor.

Variety producers are monopolistic competitors and set prices in domestic currency as in Calvo (1983): each individual producer is allowed change nominal prices with probability $(1-\theta)$. As is now well known, all producers with the opportunity to reset prices in period t will choose the same price, say $\bar{P}_t$, which satisfies:

$$\sum_{k=0}^{\infty} \theta^k E_t \left[M_{t,t+k} Y_{t+k|t} (\bar{P}_t - \frac{\varepsilon}{\varepsilon - 1} \Psi_{t+k|t}) \right] = 0 \tag{11}$$

where $Y_{t+k|t}$ is the demand in period $t+k$ for a producer that last set her price in period t :

$$Y_{t+k|t} = \left(\frac{\bar{P}_t}{P_{ht+k}} \right)^{-\varepsilon} Y_{ht+k} \tag{12}$$

$\Psi_{t+k|t}$ is the nominal marginal cost of production at $t+k$ for producers that set their prices at t, and $M_{t,t+j}$ is the period t nominal pricing kernel for payoffs in period $t+j$, as define before.

It also follows (from 9) that the price of the home final good is given by:

$$P_{ht} = \left[(1-\theta)\bar{P}_t^{1-\varepsilon} + \theta P_{h,t-1}^{1-\varepsilon} \right]^{1/(1-\varepsilon)} \tag{13}$$

2.4. Market Clearing

We assume that the foreign demand for the domestic aggregate is given by a function of its price relative to P_t^* and the index C_t^* of world consumption. Hence market clearing for the home aggregate requires:

$$Y_{ht} = (1-\alpha) \left(\frac{P_{ht}}{P_t} \right)^{-\eta} \left[C_t + \varpi \Phi(C_t, P_{ht} Y_{ht}/P_t) \right] + \phi \left(\frac{P_{ht}}{S_t P_t^*} \right)^{-\gamma} C_t^* \tag{14}$$

where ϕ is a constant and γ is the price elasticity of the foreign demand for home exports, which is allowed to differ from the domestic elasticity for the home goods, η. The first term in the right hand side is the domestic demand, inclusive of financial transfer costs, for the domestic aggregate; it uses the fact that, in equilibrium, nonfinancial household income equals the value of domestic production, that is, $H_t = P_{ht}Y_{ht}/P_t$.

As discussed later, once a rule for monetary policy is specified, the model can be solved for the equilibrium home output, consumption, and relative prices.

3. International Relative Prices, Risk Sharing, and Aggregate Supply

The possibility of imported inflation has a significant effect on the derivation of aggregate supply and the tradeoffs between output and inflation. To understand this, here we examine a first order log linear approximation of the model around a nonstochastic steady state with zero inflation.

3.1. Inflation and Marginal Costs

We shall use lowercase variables to denote logs. Starting with the pricing equations, and following Gali (2008, p.45), a first order approximation of 11 is:

$$\bar{p}_t - p_{h,t-1} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t(mc_{t+k|t} - mc) + (p_{h,t+k} - p_{h,t-1}) \tag{15}$$

where $mc_{t+k|t}$ denotes log marginal cost at $t+k$ in terms of domestic goods for those firms that set prices in period t, and $mc = \log(\varepsilon - 1)/\varepsilon$ is the steady state value of marginal costs.

Since $mc_{t+k|t} = \log(\Psi_{t+k|t}/P_{h,t+k})$,the definition of $\Psi_{t+k|t}$, 4, 12, and $N_{t+k|t} = Y_{t+k|t}/A_{t+k}$ imply

$$mc_{t+k|t} = mc_{t+k} + \varphi\varepsilon(p_{ht+k} - \bar{p}_t) \tag{16}$$

with mc_t defined as a measure of marginal cost averaged across firms:

$$mc_t = \sigma c_t + \varphi y_{ht} - (1+\varphi)a_t + (p_t - p_{ht}) + 2\varpi(c_t - h_t) \tag{17}$$

where $h_t = p_{ht} + y_{ht} - p_t = y_{ht} - \alpha q_t$ and we have ignored irrelevant additive constants, as we will hereon. The preceding expression then says that $mc_{t+k|t}$ differs from sector-wide marginal costs at $t+k$ because of the extra demand that a firm that set its price at t realizes due to the difference between that price and average prices at $t+k$. In turn, marginal costs depend on consumption c_t, average output y_{ht}, and productivity a_t in the usual way. But, because of the difference between the product wage and the consumption wage, marginal costs also depend on the price of home output relative to consumption, $p_t - p_{ht}$, and hence on the terms of trade since the linear version of 7 is

$$p_t - p_{ht} = \alpha q_t \tag{18}$$

Finally, the term $2\varpi(c_t - h_t)$ tells us that financial frictions can affect marginal costs, since they affect the consumption value of wages (see 4).

Inserting 16 into 15 and using the linearized version of 13 then leads to:

$$\pi_{ht} = \beta E_t \pi_{h,t+1} + \lambda(mc_t - mc) \tag{19}$$

where

$$\lambda = \frac{(1-\beta\theta)(1-\theta)}{\theta}\frac{1}{1+\varphi\varepsilon}$$

This relation gives current domestic (producer) inflation in terms of its expected future value and sector-wide marginal costs, and is familiar from the New Keynesian literature. Any difference that our assumptions on world food prices and financial frictions imply for aggregate supply must, therefore, are due to their impact on marginal costs.

To relate marginal costs to international relative prices, start with the log linear version of the risk sharing condition 3:

$$c_t = (1-\psi)h_t + \psi\left[c_t^* + \frac{1}{\sigma}x_t\right] \tag{20}$$

where $\psi = \sigma/(\sigma+\varpi)$. This says, remarkably, that our assumptions on risk sharing determine consumption, to first order, as a convex combination of its perfect risk sharing value (the last term in the RHS) and its autarky value.

Combining the preceding expression with 17, 18, and $h_t = y_{ht} - \alpha q_t$ then yields:

$$mc_t = (1 + 2\frac{\varpi}{\sigma})\psi(x_t + \sigma c_t^*) + [1+\varpi\psi]\alpha q_t + [\varphi - \varpi\psi]y_{ht} - (1+\varphi)a_t \tag{21}$$

This expresses how marginal costs depend on the real exchange rate and the terms of trade, in addition to domestic production y_{ht} and the exogenous shocks

a_t and c_t^*. As evidenced by the derivation, the real exchange rate x affects marginal costs because of its impact on domestic consumption (via international risk sharing) and, therefore, the disutility of labor. The coefficient on q_t reflects that the price of home output in terms of home consumption matters through the discrepancy between the product wage and the consumption wage, as we have seen, and because that price determines the consumption value of home output if risk sharing is incomplete ($\psi < 1$).

Of course, the real exchange rate and the terms of trade are both endogenous variables that are determined jointly in equilibrium. The approximate relation between them is:

$$x_t = (1-\alpha)q_t + (p_t^* - p_{ft}^*) = (1-\alpha)q_t - z_t^* \tag{22}$$

where $z_t^* = p_{ft}^* - p_t^*$ is the log of the world relative price of imports. As already stressed, if world relative prices were constant, z_t^* would be zero, and the real exchange rate would be proportional to the terms of trade, as in other models. But here world relative price changes do matter and must be taken into account. One consequence is that x_t and q_t can move in opposite directions, in response to shocks in the relative price of food.

3.2. The Phillips Curve

To derive the implications of our setting for the Phillips Curve, it is useful to focus on the differences or "gaps" between some endogenous variables and their flexible price or "natural" counterparts. This is because, if prices are flexible, monopolistic competitors would set prices as a constant markup over marginal costs, and the log of marginal cost would be constant and equal to mc. But in such a natural equilibrium, domestic output and the terms of trade would also have to satisfy a version of (21). Subtracting the natural counterpart version from the actual version of (21) and using a superscript n to indicate "natural" then gives:

$$mc_t - mc = [\varphi - \varpi\psi](y_t - y_{ht}^n) + [1 + \varpi\psi]\alpha(q_t - q_t^n) + (1 + 2\frac{\varpi}{\sigma})\psi(x_t - x_t^n) \tag{23}$$

This says that the deviation of marginal cost from its flexible price value depends on the output gap, as emphasized in the closed economy literature, but also on corresponding terms of trade and real exchange rate gaps. This expression also makes clear that the strength of the effects of these gaps on costs depend on the severity of financial imperfections.

Inserting the last equation into (19) yields a relation between inflation, the output gap, and the terms of trade and real exchange gaps. We will relate the latter to the output gap in order to arrive to a version of the New Keynesian Phillips Curve. The first step is easy : use 22 to relate the terms of trade and exchange rate gaps, so

$$x_t - x_t^n = (1-\alpha)(q_t - q_t^n) \tag{24}$$

The next step is to relate one of those gaps, say $q_t - q_t^n$, to the output gap. To do that, we use 14 and 20. The resulting expression is somewhat unwieldy, but becomes clearer in the polar cases of perfect risk sharing and financial autarky. We turn to those cases next; because of 20, the general case is just a convex combination of them.

3.2.1. The Perfect Risk Sharing Case

The perfect risk sharing case obtains with $\varpi = 0$ and $\psi = 1$. The risk sharing expression 20 then reduces to the familiar $c_t = \frac{1}{\sigma}x_t + c_t^*$. Substituting that in the linearized version of 14 and using 18 and 22 yields:

$$y_{ht} = c_t^* + q_t/\Theta - z_t^*(\frac{\omega}{\sigma} + (1-\omega)\gamma) \tag{25}$$

where ω is the ratio of domestic consumption of home goods to output in the steady state and

$$1/\Theta = \left[\omega\left(\eta\alpha + \frac{(1-\alpha)}{\sigma}\right) + (1-\omega)\gamma\right] \tag{26}$$

Subtracting from the preceding expression its "natural" version then implies the connection between the terms of trade gap and the output gap we are seeking:

$$(q_t - q_t^n) = \Theta(y_t - y_{ht}^n) \tag{27}$$

Finally, inserting this, 23, and 24 into 19 yields the New Keynesian Phillips Curve for this model:

$$\pi_{ht} = \beta E_t \pi_{h,t+1} + \chi(y_t - y_{ht}^n) \tag{28}$$

where

$$\chi = \lambda\{\varphi + \Theta\}$$

The preceding form of the Phillips curve resembles the conventional one, but the similarity can be misleading. First, the slope of the Phillips Curve (given by χ)

depends on various elasticities and parameters of the model, including the degree of openness α and the share of imports in aggregate spending $(1-\omega)$.[14] It is thus clear that this version of the Phillips curve summarizes not only the conventional effect of the output gap on marginal costs and domestic inflation, but also the effects of the terms of trade gap and the exchange rate gap on the latter. In particular, the sensitivity of the output gap to the terms of trade gap is critically dependent on the export price elasticity γ: the higher the latter, the stronger that sensitivity. This is important for our discussion later together with the fact that, in contrast with other models, we do not need to assume that $\gamma = \eta$. In fact, it is empirically arguable that η should be low, as it refers to the substitutability of food, while γ can be high.

Second, and more importantly, the natural rate of output moves around with the shocks in the model, including the world relative price shocks z_t^*. Some straightforward algebra yields the solution for the natural rate of output:

$$y_{ht}^n = \frac{1}{(\varphi+\Theta)}\left(-(\sigma-\Theta)c_t^* + \Theta\left[\omega\alpha(\eta-1/\sigma)\right]z_t^* + (1+\varphi)a_t\right) \tag{29}$$

Interestingly, if $\eta = \gamma = 1/\sigma$,the coefficients on foreign demand (c_t^*) and world food prices (z_t^*) will be zero. In this case, natural output fluctuates only in response to productivity shocks. And, perhaps more surprisingly, the sign of the response of natural output to a z_t^* shock depends only on and has the same sign as $\eta - 1/\sigma$. Natural output can rise or fall in response to food price shocks.

To understand these results, refer to Figure 3a. The MM curve is the relation between the natural terms of trade and natural output. It is derived from the marginal cost equation 17, setting $mc_t = mc$, $\varpi = 0$ and $\psi = 1$, and abstracting from from the various constant terms:

$$q_t^n = -\varphi y_{ht}^n - \sigma c_t^* + z_t^* + (1+\varphi)a_t \tag{30}$$

The DD curve is the natural version of the market clearing condition 25. Its slope is $\Theta > 0$. In Figure 3a, the natural levels of output and the terms of trade are given by a point such as E. An increase in the relative price of food, say a unit shock to z_t^*, shifts MM up by the same amount (one unit). The same shock

[14] When trade is balanced, $(1-\omega)$ exactly equals the share of spending on food imports in overall consumption spending. To see this, recall that $\omega = \frac{C_h}{Y_h} = \frac{P_h C_h}{P_h Y_h} = \frac{PC - P_f C_f}{P_h Y_h}$. Noting that $tb = 1 - \frac{PC}{P_h Y_h}$, it follows that $1-\omega = tb + \frac{P_f C_f}{P_h Y_h}$. If trade is balanced $(tb = 0)$ and with C_f being entirely met by imports, then $1-\omega = \frac{P_f C_f}{PC}$.

shifts DD up by $\Theta(\frac{\omega}{\sigma} + (1-\omega)\gamma)$. Accordingly, a positive shock to z_t^* always causes an increase in q_t^n (a deterioration in the natural terms of trade). And the shock will result in an increase in y_t^n if and only if $\Theta(\frac{\omega}{\sigma} + (1-\omega)\gamma)$ is less than unity, as in that case the vertical shift of DD will be smaller that of MM. But the sign of $[1 - \Theta(\frac{\omega}{\sigma} + (1-\omega)\gamma)]$ is equal to the sign of $\eta - 1/\sigma$. In short, under complete markets, whether a z^* shock raises or depresses natural output is theoretically ambiguous and will depend on the relative sizes of intra- vs. intertemporal elasticities.

For intuition, suppose that there is a one percent increase in z_t^*. Under flexible prices, that shock can be accommodated by only relative price movements, with no changes in home output, if $\eta = 1/\sigma$. In that case, 30 says that the terms of trade q_t^n would increase by one percent. Since $x_t^n = (1-\alpha)q_t^n - z_t^*$, the real exchange rate would then fall by α percent. But, as we have just seen, this would have no effect on demand if $\eta = 1/\sigma$. If $\eta > 1/\sigma$, however, substitution effects would prevail and the fall in the real exchange rate would result in an increase in demand. In that case, the accommodation of the shock requires an increase in the natural rate of output. Note that the strength of this would depend not only on $\eta - 1/\sigma$ but also on α and, further, on the domestic share ω in the demand for home goods. This explains why in 29 the impact of z_t^* on y_t^ndepends on $\omega\alpha(\eta - 1/\sigma)$.

3.2.2. The Financial Autarky Case

Balanced trade implies that $P_h Y_h = PC$. Taking logs and using 20 yields $c_t = y_{ht} - \alpha q_t$. This implies that a terms of trade deterioration (a rise in q_t) lowers consumption in proportion to the openness coefficient, given home output.

Substituting $y_{ht} - \alpha q_t$ for c_t in the linearized version of 14 yields

$$y_t = c_t^* + \left[\gamma + \frac{\omega\alpha(\eta-1)}{1-\omega}\right] q_t - \gamma z_t^* \tag{31}$$

Now we can proceed in the same way as under perfect risk sharing to get a New Keynesian Phillips curve, which is identical to the one under capital mobility except that Θ is given by the inverse of the coefficient of q_t in the preceding expression. The output gap is thus related to the terms of trade gap as:

$$y_t - y_{ht}^n = \left[\gamma + \frac{\omega\alpha(\eta-1)}{1-\omega}\right] (q_t - q_t^n)$$

For future reference, comparing the term in brackets above with 26, one sees that a higher export price elasticity γ will have a bigger effect on the sensitivity of the output gap to the terms of trade gap under financial autarky than under complete markets, since in the latter γ is multiplied by $(1 - \omega)$.

Again, it is instructive to examine the determination of the natural terms of trade and natural output. The DD curve in Figure 3b is the natural version of 31. Notably, the slope of DD reflects the coefficient of q_t^n in the RHS of 31, so it can be positive or negative. In Figure 3b, the DD is drawn with a positive slope, assuming that η is not too small.

To derive the MM curve under financial autarky, plug $c_t = y_{ht} - \alpha q_t$ into 17 and again use 20 to obtain (abstracting from irrelevant constants):

$$q_{ht}^n = \frac{\varphi + \sigma}{\alpha(\sigma - 1)} y_t^n + (1 + \varphi) a_t \tag{32}$$

This MM curve has two notable differences with the MM under full insurance: it does not contain z^*; and its slope is positive if and only if $\sigma > 1$.

Figure 3b depicts the MM for a value of σ over one but not too large, so that the MM cuts the DD from below. In that case, a positive z^* shock moves the DD curve up and inwards but, as noted, does not affect the MM. The natural terms of trade must deteriorate and natural output increase in response.

What if the DD has negative slope? If this is the case, the analysis remains the same provided that the MM still cuts the DD from below. The conclusions can be reversed, in principle, if the DD is so relatively steep that it cuts the MM from below. That possibility seems empirically implausible, however.

4. Aggregate Demand, Dynamics, and Impulse Responses

This section discusses the implications of our model for aggregate demand, as summarized by the New Keynesian IS curve. Then we examine the dynamic responses of the model to shocks to the relative price of food, under different parametrizations, monetary rules, and assumptions on capital mobility.

4.1. The Dynamic IS and the Natural Interest Rate

The dynamic behavior of aggregate demand can be characterized by an IS curve, where the gap between the actual interest rate and the *natural interest rate* plays a key role. For simplicity, we focus on the two polar cases of perfect international risk sharing and financial autarky. (Again, to first order, the general case is a convex combination of the two.)

We start with the perfect-risk sharing case. Linearizing the Euler condition 5 yields an expression for the real (CPI based) interest rate:

$$\begin{aligned} i_t - E_t\pi_{t+1} &= \sigma E_t \Delta c_{t+1} \\ &= E_t\left[\sigma \Delta c^*_{t+1} + \Delta x_{t+1}\right] \\ &= E_t\left[\sigma \Delta c^*_{t+1} + \Delta x^n_{t+1} + (1-\alpha)\Theta\Delta(y_{t+1} - y^n_{t+1})\right] \end{aligned}$$

where the second equality follows from the perfect risk sharing condition $c_t = \frac{1}{\sigma}x_t + c^*_t$ and the third equality comes from 22 and its natural counterpart, 24, and 27. As usual, the real interest rate is given by expected consumption growth which, with perfect risk sharing, is given by world consumption growth and expected real depreciation. Finally, expected real depreciation is determined by the depreciation of the natural exchange rate plus the growth in the exchange rate gap, which is proportional to the growth in the output gap.

One could now define a natural interest rate by the term $\sigma\Delta c^*_{t+1} + \Delta x^n_{t+1}$, but it is more intuitive to express the real interest rate in terms of domestic inflation instead of CPI inflation, since the New Keynesian Phillips curve depends on the former. To do this, we can use 20 to obtain $\pi_t = \pi_{ht} + \alpha\Delta q_t$, which combined with 24 and the last expression yields, after some rearranging,

$$y_t - y^n_{ht} = -\frac{1}{\Theta}\left[i_t - E_t\pi_{ht+1} - r^n_t\right] + E_t\widetilde{y}_{t+1} \tag{33}$$

where r^n_t defines the natural interest rate:

$$r^n_t = E_t\left[\sigma\Delta c^*_{t+1} + \Delta q^n_{t+1} - \Delta z^*_{t+1}\right] \tag{34}$$

33 is the dynamic IS curve of Woodford (2003) and Gali (2008) in an open economy with complete financial markets. It says that the output gap is determined by the interaction between a real interest rate and its natural counterpart. Rewriting it as

$$y_t - y^n_{ht} = -\frac{1}{\Theta}\sum_{j=0}^{\infty} E_t\left[i_{t+j} - E_{t+j}\pi_{ht+j+1} - r^n_{t+j}\right] \tag{35}$$

(under the assumption that the infinite sum converges) stresses that the output gap falls when the discounted sum of current and expected real interest rates exceeds the corresponding sum for the natural interest rates. In this sense, high real interest rates are contractionary but, notably, what matters is not only the current value of the real interest rate, but also the expectation of all its future values.

Recalling from the analysis of the last section that q_t^n is increasing in z_t^*, it is clear from 34 that the current output gap will be a function of the expected path of z_t^*. It can also be readily seen that the response of the natural interest rate to z^* shocks has the opposite sign of the expected growth of natural output. To see this, note that 30 implies that $q_{t+j}^n - z_{t+j}^*$ must equal $-\varphi y_{ht+j}^n$ for all $j \geq 0$, and hence r_t^n must equal $-\varphi E_t \Delta y_{ht+1}^n$. It follows that a positive z_t^* can raise or lower the natural real rate, depending on parameters. For example, if $\eta > 1/\sigma$, y_{ht}^n must increase in response to a positive z_t^* shock, as we found in the last section. Mean reversion then implies that $E_t \Delta y_{ht+1}^n$ must be negative, so the real interest rate must rise.

Consider now the financial autarky case. Recalling that balanced trade implies $c_t = y_t - \alpha q_t$ and using again $\pi_t = \pi_{ht} + \alpha \Delta q_t$, the Euler equation 5 gives:

$$i_t - E_t \pi_{ht+1} = E_t[\sigma \Delta y_{t+1} - \alpha(\sigma - 1)\Delta q_{t+1}]$$

Using this and 31, and simplifying, we obtain a dynamic IS schedule of exactly the same form as 33, but with the term

$$\sigma - \alpha(\sigma - 1)\left[\gamma + \frac{\omega\alpha(\eta - 1)}{1 - \omega}\right]^{-1} \tag{36}$$

replacing Θ, and with the real interest rate defined as

$$\begin{aligned} r_t^n &= E_t\left[\sigma \Delta y_{t+1}^n - \alpha(\sigma - 1)\Delta q_{t+1}^n\right] \\ &= -E_t[\varphi \Delta y_{t+1}^n + \alpha(\sigma - 1)(1 + \varphi)\Delta a_{t+1}] \end{aligned} \tag{37}$$

the last equality following from 32.

Notably, the response of the natural interest rate to z_t^* shocks is again equal to minus φ times the expected growth of natural output. But the latter reacts differently than under complete financial markets, as discussed at the end of last section.

4.2. Impulse Responses under Perfect Risk Sharing

The preceding discussion furnishes useful information to understand the economy's responses to z_t^* shocks under different monetary rules. Assume that risk sharing is perfect in this subsection and start with a PPI rule:

$$i_t = \phi_y(y_t - y_t^n) + \phi_\pi \pi_{ht} \tag{38}$$

Focus first on the case $\eta = 1/\sigma$. This case is the easiest because, as shown in the previous section, it implies that natural output does not react to the z_t^* shock and, also as discussed, the natural interest rate *does not* change either. Now, if the real interest rate is also expected to remain constant at all times, the dynamic IS curve implies that the output gap remains at zero. Then the Phillips curve implies that domestic inflation must also remain at zero. Finally, the PPI rule means that the nominal interest rate is also kept at zero, validating the conjecture that the real interest rate remains constant. The dotted green line in panel a of Figure 4 (which has $\eta = 1/\sigma = 0.5$) illustrates this case for a baseline calibration to be discussed below in subsection 6.1.

For an alternative perspective, consider the impact of the induced change in the real exchange rate on the demand for home output. With $\eta = 1/\sigma$, the analysis of the previous section implies that q_t^n must increase by the same amount as z_t^*. Then 22 implies that x_t^n must *fall* by that α times that amount. Assume for a moment that the world's relative price of the home good is fixed. Then the appreciation reduces the domestic relative price of home goods, pushing demand up with elasticity η. On the other hand, perfect risk sharing implies that the real appreciation must reduce domestic consumption with elasticity $1/\sigma$. If $\eta = 1/\sigma$ these effects exactly cancel each other. Hence, the real appreciation has no effects on demand if other relative prices are kept unchanged.

This reasoning implies that if $\eta > 1/\sigma$ the demand for home goods at unchanged relative prices must increase. In that case, domestic output and the output gap expand and domestic inflation becomes positive. Then the nominal interest rate must go up. As discussed in the previous subsection, the expected growth of natural output falls because of monotonic convergence, and natural interest rates increase. Then the IS curve 35 implies that the output gap must increase, the Phillips curve implies that domestic inflation increases, and the policy rule yields higher nominal interest rates. The reasoning is the opposite if $\eta < 1/\sigma$.

The responses of other variables follow easily. Note, in particular, that with η small (less than one) the interest rate response to the food price shock is also small and, given complete markets (and hence UIP), so is the nominal exchange rate response, as illustrated in Figure 4a.

Hence we find that, under perfect risk sharing, the dynamic responses of the model depend crucially on the relation between η and σ. This is noteworthy because the literature has often focused on the case $\eta = 1/\sigma$ (e.g. Gali and Monacelli

2005). Our analysis suggests that that case is one in which the importance of food price shocks is exactly minimized.

Note that, if the real exchange appreciates (as in the case $\eta = 1/\sigma$), then international risk sharing then imply that domestic consumption must *fall,* while the terms of trade deteriorate. This may be surprising and underscores the fact that, even in a flexible price world, our model is quite different from previous ones because food price shocks sever the links between the real exchange rate and the terms of trade.

We turn next to a "headline" CPI rule. For comparison, assume that the coefficients of the rule are the same as those of the PPI rule. Using $\pi = \pi_h + \alpha\Delta q$ we can rewrite this rule as:

$$\begin{aligned} i_t &= \phi_y(y_t - y_t^n) + \phi_\pi \pi_t \\ &= \phi_\pi \pi_{ht} + \phi_y(1+\alpha\Theta)(y_t - y_t^n) - \alpha\phi_\pi\Theta(y_{t-1} - y_{t-1}^n) + \phi_\pi \alpha \Delta q_t^n \end{aligned} \tag{39}$$

The above expression emphasizes that the CPI rule differs from the PPI rule in making the interest rate react to changes in the exogenous (natural) component of the terms of trade. As $\alpha\Theta > 0$, the CPI rule also puts a higher weight on the current output gap relative to the PPI rule. Finally, the CPI makes the policy rate react negatively to the lagged output gap, thus introducing an additional source of dynamics.

To understand the difference this makes, consider again the case $\eta = 1/\sigma$. We saw above that, under a PPI rule, a shock to z^* does not affect the output gap nor domestic inflation. However, the natural terms of trade must change by the same amount as z_t^*. Therefore $\Delta q_t^n > 0$ on impact, and the CPI rule prescribes that i_t must increase. This leads to a higher real interest rate and, through the dynamic IS, a fall in output and employment. The real exchange rate appreciates, so consumption falls. Analogous reasoning applies for other values of η, as shown in Figure 4b.

Note that the nominal exchange rate appreciation tempers domestic food inflation and pushes down the nominal interest rate, according to the CPI rule. From the dynamic IS equation, this imparts an expansionary effect on output. Note also that Δq_t becomes negative after a couple of periods, pulling the nominal interest rate further down. In contrast with the PPI rule, note that several of the impulse responses display a hump shape, reflecting the dynamics implied by the lagged output gap term implicit in the CPI rule, as fleshed out by our rewriting of the rule in 39.

Now consider a rule targeting *expected* CPI:

$$\begin{aligned} i_t &= \phi_y(y_t - y_t^n) + \phi_\pi E_t \pi_{t+1} \qquad (40) \\ &= \frac{\phi_\pi}{\beta}\pi_{ht} + \left[\phi_y - \phi_\pi \frac{\chi}{\beta}\right](y_t - y_t^n) + \phi_\pi \alpha E_t \Delta q_{t+1} \end{aligned}$$

where the last equality uses again the linearized CPI definition $\pi = \pi_h + \alpha\Delta q$ and the Phillips curve 28.

Some of the implications follow from the last expression. The expected CPI rule makes the interest rate react more strongly to current PPI inflation (as $\beta < 1$) but less strongly to the current output gap. More significantly, the rule reduces the interest rate in response to an expected future fall in the growth of the terms of trade. One implication is that the nominal interest rate can be much less responsive to a positive z_t^* shock.

Figure 4c shows the impulse responses to a positive z_t^* shock. Again, the case $\eta = 1/\sigma$ is the basic one. If inflation and the output gap were fixed at zero, q_t would track q_t^n and, hence, $E_t\Delta q_{t+1}$ would become negative. The expected CPI rule would then prescribe a reduction in the nominal interest rate, which would lead to lower real interest rates, and hence a boost to demand. The consequence would be a higher output gap and inflation.

Anticipating the welfare discussion in section 4, note that consumption is less volatile under this rule than under either the PPI rule or the current CPI rule. This is due to the response of the real exchange rate. On impact, the domestic CPI rises sharply (as the rule only reacts to future expected inflation rather than current inflation) but the nominal exchange rate also depreciates on impact. Hence the real exchange rate appreciates more mildly than under the PPI rule or the current CPI rule, and consumption falls by less. In short, under z^* shocks and complete markets, the expected CPI rule leads to higher output and employment, and a smaller drop in consumption than under the other two rules.

Finally, consider a nominal exchange rate peg. The first thing to note is that if $\eta = 1/\sigma$ the PPI rule implies a constant nominal exchange rate. So, under a peg, the impulse responses and the intuition are exactly the same as for that case. This is confirmed by comparing Figures 4a and 4d in the $\eta = 1/\sigma$ case. The PPI rule and the peg differ, however, if $\eta \neq 1/\sigma$. If $\eta > 1/\sigma$, as we discussed, intra-temporal substitution effects dominate and the demand for the home good, the output gap, and PPI inflation all rise. A PPI rule would then prescribe a rise in the interest rate. A peg is more accommodating, resulting in a larger increase in the output gap and PPI inflation.

4.3. Impulse Responses under Financial Autarky

As discussed in the previous section, the responses of natural variables to z_t^* under financial autarky can differ markedly from those under perfect capital mobility. The case $\eta = 1/\sigma$ no longer implies that natural output is constant under z_t^* shocks nor that $q_t^n = z_t^*$. Rather, if $\sigma > 1$, y_t^n and q_t^n react in the same direction to z_t^*. If, in addition, $\eta \leq 1$, $q_t^n > z_t^*$.

Finally, the output gap response to a z_t^* will be stronger if η is smaller. The reasoning goes as follows: our expressions for the DD and MM curves, 31 and 32, imply that y_t^n is a bigger multiple of z_t^* when η is smaller. Mean reversion in z_t^* then implies that the response of $E_t(\Delta y_t^n)$ to an innovation in z_t^* is negative, and more so if η is smaller. Correspondingly, 37 implies that the responses of the natural interest rate is positive and stronger with lower η. Finally, the dynamic IS equation implies that the output gap response is also positive and stronger with lower η. The intuition is that, under financial autarky, lower substitutability between the domestic and foreign goods implies that, in response to a positive z_t^* shock, domestic agents must produce and export more (in quantity terms) of the domestic good to maintain pre-shock consumption levels. Given that foreign demand for the home good is not perfectly elastic, this causes a deterioration of the terms of trade, so q_t overshoots z_t^*, and y_t^n and $(y_t - y_t^n)$ will both rise. In contrast, with perfect risk sharing, the economy receives an insurance payment from abroad in response to the shock. This payment is intended to stabilize the marginal utility of domestic consumption and, hence, is bigger the smaller η (as shown by the trade balance panels in Figures 4a to 4d). As domestic demand for the home good is stabilized, its supply in world markets does not increase by as much, shoring up the world price of home exports and thus preventing further terms of trade deterioration.

On the basis of this discussion, the impulse responses of Figures 5a to 5d can be readily rationalized. Consider first the PPI rule. Figure 5a shows that both natural output and the natural terms of trade rise with the z^* shock for all values of η. The natural interest rate and the output gap both rise; the response of the output gap is stronger the smaller η. Consumption falls by more than under perfect risk sharing. These implications are all in line with the analysis of the preceding paragraph.

In turn, the sharper drop in consumption and the rise in output mean that the ratio of consumption to output falls by more than under complete markets. In other words, facing a deteriorating terms of trade under financial autarky, and with imports being little substitutable by the home good, the domestic household has to reduce leisure far more per unit of consumption than under perfect risk sharing. Anticipating the results of the next section, this means that welfare will be generally lower.

Also note that, in contrast with the complete market case, the terms of trade and the real exchange rate display positive covariance when $\eta < 1$, but not for higher η. Once again, this indicates that our model can deliver different covariance patterns between those two variables, which is consistent with the data.

Consider now the headline CPI rule (Figure 5b). As with the PPI rule, both the terms of trade and natural output rise with the shock, with $\Delta q_t > \Delta z_t^*$ for $\eta < 1$. So, the real natural interest rate will rise, but the reaction of the policy rule to the rise in CPI inflation implies that $i_t - E_t\pi_{ht+1}$ rises by more than under the PPI rule. This depresses the output gap, so actual output declines despite higher natural output. Combining the fall in output with the terms of trade deterioration, consumption must fall, and more strongly if η is lower, that is, if food and domestic produce are less easily substitutable. [15]

A similar reasoning holds under the expected CPI rule, the main difference being that the interest rate response to the z_t^* shock and the contemporary rise in CPI inflation are much milder. So the real interest rate increases less than the natural rate. As a result, the output gap rises for all η and, given the rise in natural output (for the reasons discussed for previous rules), total output increases. Consumption falls, however, due to the terms of trade deterioration, and by more than under perfect risk sharing if $\eta < 1$ (although not so for higher η). So, if $\eta < 1$, consumption is lower and output higher than under complete markets under the same policy rule, leading to a larger welfare loss.

Finally, and for analogous reasons, the peg rule delivers lower output and lower consumption than under perfect risk sharing if the imported good has a "food-like" low substitution elasticity, in this case $\eta < 1$.

5. Welfare and Policy Trade-Offs

Our model economy is not completely "small", since nominal rigidities imply that monetary policy affects relative prices, including the price of the home aggregate in terms of world consumption. Hence in this model and similar ones, policy choices must take into account not only the distortions caused by nominal rigidities but

[15] Notably, this corroborates Jeff Frankel's argument that the CPI rule is broadly pro-cyclical in terms of the reaction of output and consumption to a terms of trade deterioration.

also the associated relative price effects (known as *terms of trade externalities*), as known since Corsetti and Pesenti (2001).

This section discusses how this trade-off plays out in our model. Following Faia and Monacelli (2008) and Catao and Chang (2013), it is quite informative to compare the solution of the social planner's or *Ramsey* problem against the *natural* allocations that would emerge in a flexible price competitive equilibrium. As in Catao and Chang (2013), and unlike Faia and Monacelli (2008), we manage to provide a useful and tractable description of Ramsey allocations and natural allocations. The two polar cases of complete markets and financial autarky are examined in particular detail. The analysis goes a long way towards clarifying the welfare implications of different policy rules, if only because it demonstrates how and why Ramsey allocations can differ from natural ones, which are well approximated by PPI targeting.

5.1. Social Planner's vs. Flex-Price Market Allocation

To simplify notation (and without loss of generality), normalize κ to 1. Using 8, the market clearing condition for home goods, 14, can be written as:

$$A_t N_t = (1-\alpha) g(X_t Z_t)^\eta C_t + \phi X_t^\gamma g(X_t Z_t)^\gamma C_t^* \tag{41}$$

where P_t/P_{ht}, the (inverse of the) real price of home output, has been written as a function of the real exchange rate and the food price shock:

$$\frac{P_t}{P_{ht}} = g(X_t Z_t) = \left\{ \frac{1-\alpha(X_t Z_t)^{1-\eta}}{1-\alpha} \right\}^{1/(\eta-1)} \tag{42}$$

Equation 41 must hold at all times and is a key constraint for the planner's choices of consumption, leisure, and the real exchange rate.

Another key constraint is the international risk sharing equation 3, which amounts to

$$C_t^\sigma \left[1 + \varpi \Phi(C_t, A_t N_t / g(X_t Z_t))\right] = X_t \left(C_t^*\right)^\sigma \tag{43}$$

after recalling that $H_t = P_{ht} Y_t / P_t = A_t N_t / g(X_t Z_t)$.

The Ramsey problem is then to maximize $u(C_t) - v(N_t)$ subject to 41 and 43. Remarkably, the problem is static: the Ramsey planner solves the same problem at each date, in each state. This means that a solution of the Ramsey problem is quite tractable, even in the general case. But for expositional purposes, and also to facilitate comparison with previous literature, it is useful to focus on the polar extremes of perfect risk sharing and portfolio autarky.

5.2. Policy Trade-offs Under Perfect Risk Sharing

Perfect international risk sharing implies that 43 reduces to 3: $C_t = C_t^* X_t^{1/\sigma}$. Inserting this into 41 and the objective function, the Ramsey problem then reduces to

$$\text{Maximize } \; u(C_t^* X_t^{1/\sigma}) - v(N_t)$$

subject to

$$A_t N_t = C_t^* \Theta(X_t, Z_t) \tag{44}$$

where

$$\Theta(X, Z) = (1-\alpha) g(XZ)^{\eta} X^{1/\sigma} + \phi X^{\gamma} g(XZ)^{\gamma}$$

The first order optimality condition can be written as

$$\frac{1}{\sigma} C_t u'(C_t) = v'(N_t) N_t \epsilon_{Xt}^{\Theta} \tag{45}$$

where ϵ_{Xt}^{Θ} denotes the elasticity of Θ with respect to X_t[16].

This formulation of the Ramsey problem and its solution makes the policy tradeoffs quite transparent . The planner equates the marginal benefit of a one percent real depreciation, given by the LHS of the preceding equation, to the cost, given by the RHS. By perfect risk sharing, the real depreciation raises consumption by $1/\sigma$ percent, or C_t/σ units. On the other hand, the real depreciation of one percent raises world demand for the home good by ϵ_{Xt}^{Θ} percent. This requires labor effort to increase by $N_t \epsilon_{Xt}^{\Theta}$ units.

The Ramsey allocation is then given by 3, 44, and 45. Two remarks are in order:

- The optimal solution (C_t, N_t, X_t) is stochastic and generally time varying, since it solves the system 3, 44, and 45 which depends on the shocks Z_t and A_t.
- The elasticity of Θ with respect to X_t, ϵ_{Xt}^{Θ}, is generally time varying and, more crucially, summarizes the role of the different elasticities of demand and substitution in the model. And in fact, it is ϵ_{Xt}^{Θ} that determines the

[16] Letting the elasticity of g be denoted by $\epsilon_{XZ,t}^{g} = \alpha(X_t Z_t)^{1-\eta}/(1-\alpha(X_t Z_t)^{1-\eta})$, then

$$\epsilon_{X,t}^{\Theta} = \frac{(1-\alpha) g(X_t Z_t)^{\eta} X_t^{1/\sigma}}{\Theta} [\eta \epsilon_{XZ,t}^{g} + \frac{1}{\sigma}] + \frac{\phi X_t^{\gamma} g(X_t Z_t)^{\gamma}}{\Theta} [\gamma + \gamma \epsilon_{XZ,t}^{g}]$$

incentives for the planner to exploit the "terms of trade externality". A one percent depreciation, under perfect risk sharing, always increases consumption by $1/\sigma$ percent, but the size of the associated increase in labor effort, with the resulting cost, is smaller or larger depending on ϵ_{Xt}^{Θ}. This implies, *a fortiori,* that the relative desirability of different policy rules will depend on the interplay between elasticities and how much each rule attempts to exploit the terms of trade externality.

As an alternative to the Ramsey allocation, we can compute the *natural* allocation, that is, the allocation that would emerge in a market equilibrium in the absence of nominal rigidities. In any flex price market equilibrium, prices set as a markup over marginal cost, $P_{ht} = \mu MC_t = \mu(1-\upsilon)W_t/A_t = \mu(1-\upsilon)W_t/A_t$. And since $W_t/P_t = \upsilon'(N_t)/u'(C_t)$ we get, after using $P_t/P_{ht} = g(X_tZ_t)$:

$$\frac{\upsilon'(N_t)}{u'(C_t)} = \frac{A_t}{\mu(1-\upsilon)g(X_tZ_t)} \tag{46}$$

The natural allocation is therefore pinned down by 3, 44, and 46.

Now note the following:

- The Ramsey allocation and the natural allocation will, in general, differ because (and only because) the Ramsey optimality condition 45 are not the same. The basic difference is, in fact, the terms of trade externality: the Ramsey planner takes into account the impact of its policies on the real exchange rate, while the natural allocation ignores that impact. To see this, assume that $\mu(1-\upsilon) = 1$. Then the preceding expression for the natural allocation reduces to $\upsilon'(N_t) = u'(C_t)A_tP_{ht}/P_t$, which is easily seen to be the optimal labor choice condition for a planner that takes the relative price P_{ht}/P_t as given.

- Complete PPI stabilization will result in the natural outcome. But the latter is different, in general, from the Ramsey allocation. Hence the optimality of PPI, a mainstay of the literature, hinges on how far apart the Ramsey and natural allocations can be. Again, this will depend on the parameters underlying the functions Θ and g, since they determine the difference between 45 and 46.

- Our analysis here clarifies many of the results in the literature. For example, if $\eta = \gamma = 1/\sigma$, 45 and 46 coincide exactly provided that $\mu(1-\nu) =$

$1 + \phi/(1-\alpha)$. Under the additional assumption $\alpha = \phi$, this is Gali and Monacelli's (2005) condition for PPI stabilization to be optimal (the so called *divine coincidence*). Clearly, however, this is a very special case.

5.3. Policy Trade-Offs Under Financial Autarky

As ϖ becomes arbitrarily large, the risk sharing condition 43 implies financial autarky, $P_{ht}Y_{ht} = P_t C_t$, which can be written as:

$$C_t = A_t N_t / g(X_t Z_t) \tag{47}$$

One can then use this in the objective function and 41 to write the Ramsey problem as:

$$\text{Maximize } u(\frac{A_t N_t}{g(X_t Z_t)}) - v(N_t)$$

subject to:

$$A_t N_t = (1-\alpha) g(X_t Z_t)^{\eta} \frac{A_t N_t}{g(X_t Z_t)} + \phi X_t^{\gamma} g(X_t Z_t)^{\gamma} C_t^*$$

This emphasizes the underlying trade-offs under portfolio autarky. As before, given domestic consumption, a real depreciation increases demand via expenditure switching. But the depreciation also reduces the purchasing power value of home output, leading to lower consumption. This has an offsetting effect on the world demand for output and the demand for labor. Hence the incompleteness of financial markets changes the terms of the trade-off for the Ramsey planner.

The first order optimality condition can be written as:

$$\frac{v'(N_t)}{A_t} D_t [\epsilon^D_{Xt} - \epsilon^D_{Ct} \epsilon^g_{XZt}] = u'(C_t) C_t [\epsilon^D_{Xt} - \epsilon^g_{XZt}] \tag{48}$$

where D_t denote the world demand for home goods (the RHS of 41), a function of C_t, X_t , and exogenous shocks, while ϵ^D_{Xt} is the elasticity of D_t wrt X_t, etc. [17]

The condition is again quite intuitive. The planner balances the utility cost, in terms of labor effort, of a one percent real depreciation, against the utility benefit

[17] Here, $\epsilon^D_{Ct} = (1-\alpha) g(X_t Z_t)^{\eta} C_t / D_t$ and

$$\epsilon^D_{Xt} = \frac{(1-\alpha) g(X_t Z_t)^{\eta} C_t}{D_t} \eta \epsilon^g_{XZt} + \frac{\phi X_t^{\gamma} g(X_t Z_t)^{\gamma} C_t^*}{D_t} (\gamma + \gamma \epsilon^g_{XZt})$$

in terms of increased consumption. In the LHS, the term in brackets is the total percent increase in demand for the home aggregate (the direct effect on demand minus the indirect effect via home consumption). So the LHS product is the utility cost of the additional labor needed to accommodate the increased demand due to the depreciation. In the RHS, the term in brackets is the percentage increase in consumption, equal to the percentage increase in output minus the percentage its relative price. The RHS is, then, the increase in utility associated with the additional consumption resulting from the one percent depreciation.

The Ramsey allocation is given by the preceding condition together with 41 and 47. On the other hand, the flex price market outcome, which is also the outcome of full PPI stabilization, is given by 41, 46, and 47.

As with the perfect risk sharing case, the Ramsey allocation and the natural outcomes will differ in general, due to the discrepancy between 48 and 46. Again, in particular, the equations tell us in a precise way how our assumptions about elasticities translate into wedges between Ramsey and natural allocations under portfolio autarky, therefore affecting the desirability of PPI stabilization. In this case, however, finding conditions for the divine coincidence (which reduces to the equality of 46 and 47) is not as tractable as under perfect risk sharing. For additional results one must then turn to numerical methods. This is pursued next.

6. Welfare Implications in a Calibrated Version of the Model

6.1. Calibration

The stochastic processes governing the different shocks in the model, particularly those related to z^*, are critical for our welfare results. The time period is taken to be a quarter and we assume that all exogenous shocks are AR(1). The baseline calibration for the z^* assumes a standard deviation of five percent and a persistence coefficient of 0.85. This is consistent with regressions of the (log of the) IMF global index of food commodity prices relative to the US WPI between 2000Q1 and 2011Q4.[18] For productivity shocks, we set the standard deviation at 1.2 percent and the persistence parameter at 0.7. These values were based on estimates from

[18] The regression includes a constant and time trend. Moving start forward up to 5 years yields standard deviations of the regression residual in the 5% to 6% range and AR(1) coefficient between 0.83 and 0.90. If instead z* is detrended by an HP filter (lambda=1600), the respective AR(1) regression yields a standard deviation of the residual of 5.2% and AR(1) coefficient of 0.64. These differences in persistence estimates do not affect, however, our main welfare results.

Chile, a typical small open economy (Chile) [19], and are also consistent with the ones in Gali and Monacelli (2005)[20]. Finally, in order to calibrate shocks to monetary policy rules, we estimated a Taylor rule-type regression with Chilean data from 1991 to 2008. The resulting values were 0.62 percent for the standard deviation and 0.6 for persistence.

The transfer cost parameter ϖ is calibrated using $\psi = \sigma/(\sigma + \varpi)$, so that $\psi \in [0, 1]$. As noted, $\psi = 1$ implies that markets are complete, whereas $\psi = 0$ represents the financial autarky case. From US household data, Schulhofer-Wohl (2011) reports a median estimate of $(1-\psi)$ in the 0.1 to 0.15 range. As one might expect cross-border risk sharing to be lower than domestic risk sharing, $\psi = 0.9$ is clearly an upper bound. Besides the complete market and financial autarky extremes, we explored the cases with $\psi = 0.9$ and $\psi = 0.5$, although we only report the former here to save space.

Two other parameters critical to our welfare results, as seen below, are the price elasticity of foreign demand for the home aggregate, γ, and its relation to the elasticity of substitution of the domestic consumption index, η. Previous studies have assumed that $\gamma = \eta$, although there is no compelling reason to impose the equality, specially given the assumed high degree of differentiation between imported goods (food) and exported goods (manufacturing/services) that motivate our model. Hence we allow γ to differ from η . Using aggregate data from advanced economies, Hooper, Johnson and Marquez (2000) reported estimates around one. However, the relevant elasticity in our model is that of a sticky price sector; if that sector is manufacturing in an emerging economy, it is likely to produce less complex/differentiated varieties than in advanced countries, arguably facing a much flatter world demand schedule.[21] Cross-country econometric studies report estimates of the price elasticity of manufacturing goods of around 5 (Lai and Trefler 2002, Harrigan 1993).

[19] Even though Chile is a commodity (rather than a manufacturing or service) exporter at the same time that is a net food importer, the good quality of its data and long-standing adherence to inflation targeting make it a particulary useful choice for one's benchmarking of TFP and monetary shock calibration in a small open economy.

[20] Gali and Monacelli (2005) calibrated their model to Canadian data and reported standard deviations of TFP shocks of nearly half (0.7 percent) the value we assume. This is consistent with the fact that output in the Chilean economy has been about twice more volatile than in Canada.

[21] Indeed, it seems likely that lightly processed manufactures exported by many emerging countries are much more easily substitutable in world markets than, say, complex hardware and software equipment, optical and machine tool parts, and other items exported by, say, the US, Germany, and Japan.

The ratio of home good consumption to income in steady-state (ω) is set to 0.66, consistent with food expenditure shares in GDP of around thirty percent, the cross country average (cf. Table 2). In the nonlinear representation of the model's steady state ω is a function of ς, κ,and Y^*, so one of these parameters is determined by the choices on the other two. Since we have no evidence for a realistic calibration of ς, we fix $\kappa C^* = 1$ and choose relative prices in steady state so that trade is balanced and the representative household allocates about a third of time to leisure, i.e., $1 - L = 0.66$. These two assumptions pin ς down .

Other parameters are more common in the literature and calibrated as reported in Table 5. Values for intra- and inter-temporal elasticities are standard from previous studies[22]. In the particular case of the labor supply parameter φ, for which estimation variance is higher, we evaluate results for a wider parameter range, from $\varphi = 1$ to $\varphi = 0$.

Finally, the parameters of policy rules are calibrated as follows. Using the baseline calibration for other parameters (with $\gamma = 5$ and $\sigma = 2$, but letting η vary) we computed discounted utility values resulting from varying the coefficients of the PPI and the CPI rules over a grid spanning from 1.5 to 5 (with 0.25 increments) for the coefficient on inflation (ϕ_π), and from 0 to 0.5 (with 0.125 increments) for the coefficient on the output gap (ϕ_y). For both the PPI and expected CPI rule, fixing ϕ_y =0.125 (corresponding to about 0.5 on annual data) yields values of ϕ_π of 2.05 and 1.85, respectively, for which those rules are optimized.[23] For the (conventional) CPI rule, the optimizing coefficient on inflation was a little lower, around $\phi_\pi = 1.65$. Accordingly, in what follows we set $\phi_\pi = 2.05$ for the PPI rule, $\phi_\pi = 1.85$ for the expected CPI rule and $\phi_\pi = 1.65$ for the current CPI rule, with $\phi_y = 0.125$ for all three rules. Finally, for the peg rule, we need to calibrate the stochastic process for the world consumer price index. We let it evolve according to an stochastic process with considerable persistence ($\rho = 0.99$) and standard deviation of 1.3 percent, as obtained from a quarterly AR(1) regression of an unweighted average of advanced countries (G-8) producer price indices during the 1990-2008 period.[24]The baseline calibration is summarized in Table 2.

[22]On the intra-temporal substitution elasticity η , the chosen range conforms with estimates from Annand and Prasad (2012) lying in the 0.1 to 0.4 range, based on WDI and USDA sources.

[23]A coefficient of 0.125 on the output gap on quarterly data is also found in previous work. See, e.g., Bodenstein, Erceg and Guerrieri (2008).

[24]Restricting estimation to the pre-2008 mitigates potential small sample biases due to the deflationary effects of the 2009-10 financial crisis but either way, our results are not critically affected by the choice of this estimation window.

6.2. Welfare Metrics

For each version of the mode, we computed a second order approximation to the utility of the representative household, following Wang (2006), Schmitt-Grohe and Uribe (2007), and others. Our welfare metric is conditional on the same starting point which, as in the cited studies, is the non-stochastic steady state.[25]

We then computed the welfare loss associated with each policy rule as a percentage of steady consumption (C_{ss}). For the PPI rule, for instance, losses relative to steady state were given by:

$$\lambda_{ppi} = 1 - \frac{(1-\sigma)^{1/(1-\sigma)}}{C_{ss}} \left[U_{ppi}(1-\beta) + \zeta \frac{N_{ss}^{1+\varphi}}{1+\varphi} \right]^{1/(1-\sigma)}$$

In the tables we report the relative welfare of pairs of rules. For example, the relative performance of the PPI rule against the CPI rule is given by $-100 \times (\lambda_{ppi} - \lambda_{cpi})$, and hence expressed as a percentage of steady state consumption.[26]

Before moving on to the numerical results, it may be useful to elaborate further on how the welfare analysis depends on two novel aspects of our model: the possibly distinct covariance pattern between food price shocks, the terms of trade and the real exchange rate); and imperfect risk sharing. The welfare of the representative household depends directly on the probability distributions of consumption and labor effort, but these distributions will depend on other endogenous and exogenous variables in a way that depends on risk sharing. For instance, perfect risk sharing we have the exact relation $c_t = c_t^* + \frac{1}{\sigma} x_t$. This means that the policymaker has an incentive to reduce the volatility of real exchange rates. Doing that, on the other hand, can be shown to raise the domestic price level on average, and hence to lead to a stronger real exchange rate and a fall in mean consumption, to an extent that depends on the covariance between x_t and z_t. So reducing exchange rate volatility has costs that depend on that covariance. And, of course, these links will themselves change if international risk sharing is imperfect.

6.3. Welfare Results

Our first set of results assume complete markets. For the baseline parameterization, Table 3 summarizes the relative welfare implications of the alternative policy

[25] Computationally, this calculation amounts to a simple addition of a control variable V_t to our system of non-linear equations, where V_t evolves according to the law of motion $V_t - \beta V_t = U(C_t, N_t)$.

[26] With logaritmic utility, the formula is $100 \times (e^{(1-\beta)(V_0^{ppi} - V_0^{cpi})} - 1)$.

rules. Except for the peg, "strict " inflation targeting (a zero coefficient on the output gap) is assumed for each rule. For each given pair of rules, each panel in the table reports the negative of the difference of the welfare cost of the two rules, in percentages of steady state consumption, so that a positive number means that the first rule in the comparison is superior to the second one. Each panel, in turn, examines combinations of σ (rows) and η (columns). The welfare magnitudes are small, as typical in the literature. The summary matrix at the bottom of the table shows the overall winner for each combination of η and σ.

In our model, Table 3 indicates that, when markets are complete, the conventional belief on the dominance of PPI targeting is unwarranted. The first matrix of the table shows, for example, that CPI targeting beats PPI targeting unless $\sigma = 1$ and $\eta \leq 1$. More markedly, the PPI rule is most decisively beaten by the expected CPI rule, with the welfare gaps exceeding half a percent of steady state consumption for η sufficiently high. These findings are consistent with the theoretical claims of Faia and Monacelli (2008) as well as with the calibration results of Cova and Sondergaard (2004) and di Paoli (2009), as these papers study similar models in which, under complete markets and strict inflation targeting, the PPI rule loses out to others when η is sufficiently high. What is new here is that expected CPI targeting, a rule that was not considered in previous studies, appears superior to all others. Also, it may be noted that all welfare gaps over the PPI rule are larger than those reported in previous work.

To isolate the contribution of exogenous shocks to imported food prices to these results, Table 4 examines the same case as in Table 3 except that import price volatility is set to trivial levels ($\sigma_z = 0.001$). Then our model becomes quite close to the canonical new Keynesian model. Indeed, we replicate a main theoretical result of Gali and Monacelli (2005), that PPI welfare dominates other rules if $\eta = \sigma = 1$. In fact, PPI targeting remains as the best rule whenever $\eta \leq \sigma$. Together with the results of Table 3, these estimates highlight a notable fact: the PPI rule tends to dominate others when the imported consumption good displays (food-like) low intratemporal substitution elasticities. In addition, Table 4 confirms the result in Cova and Sondergaard (2004) and di Paoli (2009) that an exchange rate peg is best when σ is sufficiently high, although this finding is qualified for high values of η, in which case expected CPI targeting has an edge (albeit marginal) over the peg. Finally, the relative magnitudes of the welfare gaps in Tables 5 and 6 indicate that high imported price volatility can substantially increase the welfare differences across rules, a fact already noted but perhaps worth repeating.

Table 5 returns to the baseline parameterization of Table 3 but allows for a nonzero (ϕ_y =0.125) coefficient on the output gap in Taylor rules. The rankings are very similar to those in Table 5, the main difference being that a positive weight on the output gap improves slightly the relative performance of the PPI rule (so that that rule now beats the others if $\sigma = 2$ and $\eta = 0.25$). This is readily understood from equations 39 and 38: a higher weight on the output gap makes the PPI closer to a CPI rule. Still, expected CPI targeting dominates for most parameter combinations.

In order to shed further light, Table 6 summarizes simulated means and standard deviations of main observables for each rule. For comparison, the implications of the Ramsey plan and the natural flex price equilibrium are included. We focus on the case of $\eta = 1/\sigma = 0.5$ in order to illustrate what the low elasticity of "food-like" goods can do to welfare, but the thrust of the argument holds for higher elasticity values.

The case of perfect risk sharing corresponds to the left panel of Table 6. Start with the differences between the Ramsey allocation and the natural one. The Ramsey allocation requires less exchange rate volatility than the natural outcome. This leads to less consumption volatility but more employment variability. In terms of means, the main difference is that the Ramsey plan results in lower labor effort on average than the natural allocation. As a consequence, the mean consumption to output ratio is slightly higher for the Ramsey plan.

Turning now to the different rules, Table 6 shows that, under perfect risk sharing, PPI targeting approximates the natural allocation in most dimensions. The notable exception is the much higher employment volatility under the PPI rule. This occurs because the (optimized) PPI rule features a positive weight on the output gap. Hence the PPI rule ends up allowing for nonzero producer inflation and associated nonzero variation in intersectoral price dispersion, which results in higher employment volatility than the zero inflation, natural counterpart.[27] The other columns, however, show that the other policy rules result in an even higher value for employment volatility. How is, then, that the expected CPI rule dominates the others? A main reason, the table shows, is by relying more heavily on the terms of trade externality. Expected CPI targeting stabilizes the real exchange rate and hence consumption, so that their variability becomes close

[27] Up to second order, aggregate employment is given by $N_t = \frac{Y_t}{A_t}(1 + du_t)$ where du_t varies with the inflation rate. In the natural allocation, $du_t = 0$. Under a PPI rule, this will only be so under strict inflation targeting and/or sufficient high Taylor coefficient on PPI inflation so that producer prices are fully stabilized.

to the Ramsey values. Notably, this also implies that the expected CPI rule results in a significantly stronger average real exchange rate than the Ramsey plan, and hence in a lower mean value for consumption; but the latter is more than compensated with a lower value for mean labor effort, so that the mean consumption-output ratio is highest among all the alternatives.

It is also instructive to compare the implications of the expected CPI rule against those of the (current) CPI rule. The latter does not stabilize the real exchange rate as much as the expected CPI rule; in fact, the conventional CPI rule delivers more real exchange rate variability than the PPI rule. Notably, both consumption variability and labor effort variability are higher with CPI targeting than with the PPI rule. CPI targeting, however, does manage to raise the mean consumption-output ratio above the PPI value.

Finally, note that an exchange rate peg results in more real exchange rate variability than the PPI rule and the expected CPI rule. This means that consumption variability is greater, while not reducing variability of labor employment, which in fact becomes much greater.

The right panel of Table 6 illustrates how the analysis changes when international risk sharing is no longer complete. The changes are starkest under the polar case of financial autarky. Yet, as discussed below, they begin to take effect once ψ is smaller but not too much smaller than one. A first thing to notice is that, under portfolio autarky, the Ramsey planner allows for much more volatility in consumption and employment than under the natural allocation. In fact, the standard deviations of consumption and employment are much larger than under perfect capital markets. This suggests that the Ramsey plan exploits the terms of trade externality less. This is confirmed by the observation than the expected CPI rule no longer delivers a consumption volatility value that is closest to Ramsey. Instead, it reduces consumption volatility too much relative to the optimal value (0.342 vs. 1.236), at the cost of much greater employment volatility (1.013 vs. 0.387). Both PPI targeting and the CPI rule allow for more consumption volatility to gain less employment variability, with the PPI rule getting closer to the Ramsey values. Since mean values are not very different across rules, the PPI rule dominates the welfare comparison.

This analysis is further corroborated in Table 5, which reports welfare results for the same parameterization as Table 3 but now with $\psi = 0.9$, hence imperfect risk sharing. The table confirms the crucial role of imperfect risk sharing in welfare rankings: now PPI targeting dominates the other rules for most parameterizations.

Some elaboration on the plausibility of the case $\psi = 0.9$ is in order. While ψ

= 0.9 may look like a very small departure from full risk sharing case ($\psi = 1$), this perception is misleading. Estimates of the risk sharing equation 50 of the Appendix, using a broad cross-country panel, yield $\varpi/\sigma = 1/\psi - 1$ in the range of 0.1 to 0.2;[28] taking the lower bound and $\sigma = 4$,this implies ϖ~0.4. An estimate of $\psi = 0.9$ is, in fact, remarkably close to what Schulhofer-Wohl (2011) obtained using US household data and more elaborate estimation approaches. So setting $\psi = 0.9$ does appear to be a natural benchmark to consider as an alternative to full risk sharing.[29]

The last three tables explore the role of three critical parameters. The first one is the price elasticity of the world demand for the home aggregate, γ. Changes in γ affect the world elasticity of demand for the home aggregate, but the impact on the policymaker's incentive to appreciate or depreciate the real exchange rate is hard to derive analytically and depends on the degree of risk sharing (compare 45 versus 48). Assuming that $\psi = 0.9$, Table 8 summarizes welfare effects when γ drops from its baseline value of 5 to 1. PPI clearly becomes more dominant. This is of interest as it suggests that imperfections in international *goods* markets (here, lower trade price elasticities) can amplify the effect of international financial frictions, resulting in PPI having a greater edge over other rules.

Table 9 illustrates the effects of letting the labor supply be more elastic, in fact infinitely so ($\varphi = 0$). Strikingly, it dents the PPI dominance only marginally. The PPI rule remains best when $\eta < 4$, that is, in the low η range that typically characterizes "food".

Finally, Table 10 explores the implications of less severe nominal rigidities by dropping the Calvo parameter θ to 0.4. This value implies that domestic variety producers set prices every 1-2 quarters on average. Under the assumption $\psi = 0.9$,

[28]Estimates based on annual data spanning 66 advanced and emerging economies over the period 1980-2011, all data from IMF/IFS and World Bank WDI databases. GLS panel regressions with country-level clustered standard errors and using first-order lags of right hand side variables to mitigate endogeneity deliver estimates of ϖ/σ closer to 0.1. *Alternatively*, 2SLS/IV estimation with lagged changes in the real exchange rate and in the consumption/output ratio (together with a time trend and country fixed effects) as instruments, one obtains point estimates around 0.2. Specifics of the underlying estimation and data are available from the authors upon request. Needless to say, these estimates should be taken as preliminary benchmarks for our calibration, given the absence of previous cross-country estimates for the chosen transfer cost function. A more detailed empirical investigation of that function is, however, beyond the scope of this paper and left for future research.

[29]Some further sensitivity analysis indicate that the reversal of welfare rankings occurs for a value of ψ indicates around 0.95.These results are not fully reported here to save space but available from the authors upon request.

Table 10 shows that the PPI rule remains best as long as $\eta < 4$, which is the realistic range.

Tables 8-10 indicate that, of the parameters considered, the export price elasticity γ has a relatively greater effect on welfare rankings. Again, the main intuition is that γ affects the elasticity of the world demand for the home aggregate, and hence the Ramsey planner's incentive to exploit the terms of trade externality. Decoupling γ and η allows to see this clearly in our model, unlike previous ones which assumed $\gamma = \eta$.

7. Conclusion

The large swings of world food prices in recent years have posed serious challenges for monetary policy, especially for countries where food commodities have a higher weight in consumption. These countries have faced greater inflationary pressures and appreciating real exchange rates; net food importers have also experienced worsening terms of trade. Except for very particular elasticity configurations, stabilizing inflation will not be isomorphic to stabilizing the output gap in this setting; instead, the trade-off between stabilizing producer prices vs. stabilizing the real exchange rate and consumption is exacerbated.

This paper has analyzed the implications for monetary policy by introducing some key modifications to the canonical small open economy New Keynesian model. These include decoupling the export price elasticity of the foreign demand for the home good from the intratemporal elasticity of substitution in consumption between the home and (food) imports, and allowing for international risk sharing. Our results corroborate some of the prevailing wisdom regarding the desirability of PPI targeting, but also show that that is not a one-size-fits-all rule. Under full international risk sharing and sufficiently high export demand elasticities, we broadly confirm the welfare superiority of CPI inflation targeting highlighted in the work of Cova and Sondergaard (2004) and di Paoli (2009). But we also find that, if shocks to world food prices are nontrivial, expected CPI targeting generally outperforms conventional CPI targeting, a novel result in the literature. In another departure from the literature, we show that deviations from perfect risk sharing, here due to costs in international transfers, can be crucial for policy rankings and, in particular, can restore the clear supremacy of PPI stabilization.

The analysis has several noteworthy implications. First, the rationale for broad CPI targeting, as currently adopted by many central banks, is strengthened if world capital markets function rather well. Even then, when food price shocks are large, forecast CPI inflation targeting welfare-dominates the more hawkish current CPI inflation targeting. Importantly, the welfare gap between these two rules increases with the volatility of imported (food) commodity inflation.

Another main implication is that the desirability of PPI targeting vis a vis CPI targeting depends on the structure of the economy and, crucially, on the composition of exports and the degree of financial imperfections. Countries which specialize in goods with a high price elasticity of demand for their exports benefit more from CPI targeting or, if elasticities are particularly high, pegging the exchange rate. This is all the more so the more elastic the supply of labor, as the latter helps mitigate the impact of imported price shocks on costs. On the other hand, if international risk sharing is incomplete and goods markets are imperfect, in the sense of having low intratemporal elasticicities, the case for targeting PPI, or a variant such as "core" CPI, is strong.

Appendix

Here we derive implications of our specification of financial market imperfections in section 2, especially 3 and 20. Our assumptions change the standard first order conditions of the household as follows: let $Q_{t,t+1}$ denote the domestic currency price at t of a security that pays a unit of domestic currency at $t+1$ conditional on some state of nature s' being realized at that time. Then optimal consumption requires:

$$Q_{t,t+1} = \beta \frac{P_t}{P_{t+1}} \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{1 + \varpi \Phi_c(C_t, H_t)}{1 + \varpi \Phi_c(C_{t+1}, H_{t+1})}$$

where C_{t+1}, H_{t+1} are consumption and current household income at $t+1$ in the state of nature s'. The intuition for this is that the cost of an extra unit of consumption at t is not P_t but $P_t(1 + \varpi \Phi_c(C_t, H_t))$, in order to take into account the associated transfer cost.

For the rest of the world, we assume that there is no transferring cost, so the corresponding FOC is

$$Q_{t,t+1} = \beta \frac{S_t P_t^*}{S_{t+1} P_{t+1}^*} \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma}$$

Hence, the usual derivation for the complete markets case can be amended to yield:

$$P_t C_t^{\sigma} \left[1 + \varpi \Phi_c(C_t, H_t)\right] = \kappa S_t P_t^* \left(C_t^*\right)^{\sigma} \tag{49}$$

which is equivalent to 3.

To derive 20, take logs in 3 to obtain:

$$\sigma c_t + \log(1 + \varpi \left[(c_t - h_t) + \frac{1}{2}(c_t - h_t)^2 \right]) = \log \kappa + \sigma c_t^* + x_t \tag{50}$$

To first order, $\log(1 + \varpi \left[(c_t - h_t) + \frac{1}{2}(c_t - h_t)^2 \right]) = \varpi (c_t - h_t)$, so the expression above reduces to 20, aside from an irrelevant additive constant.

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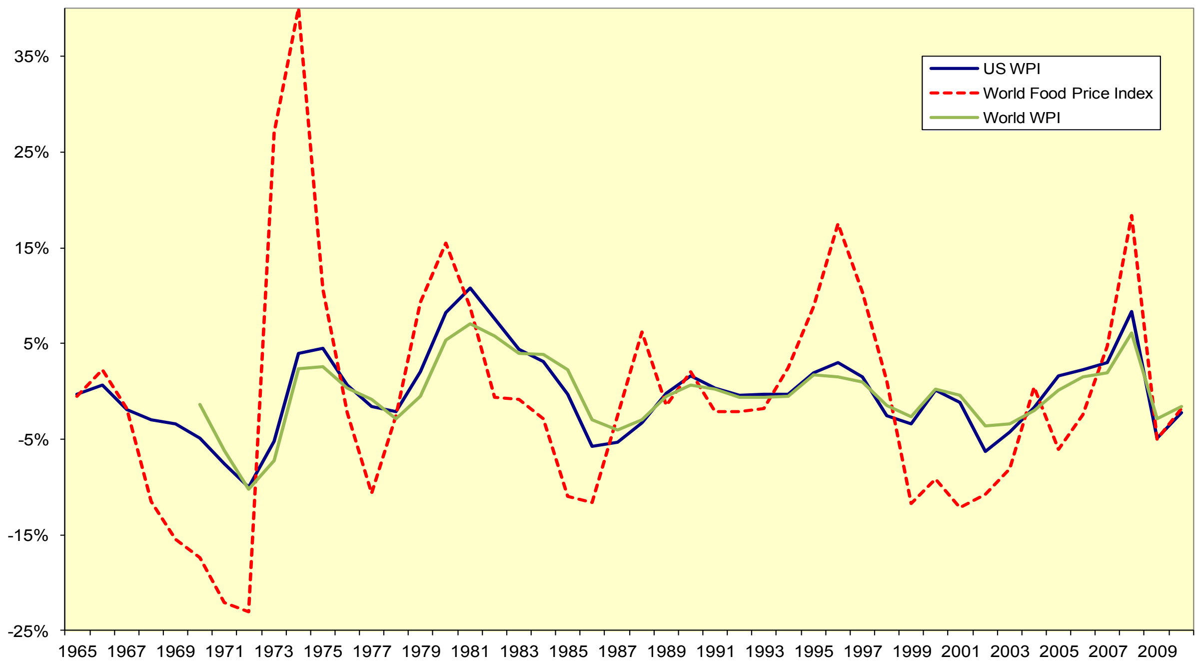
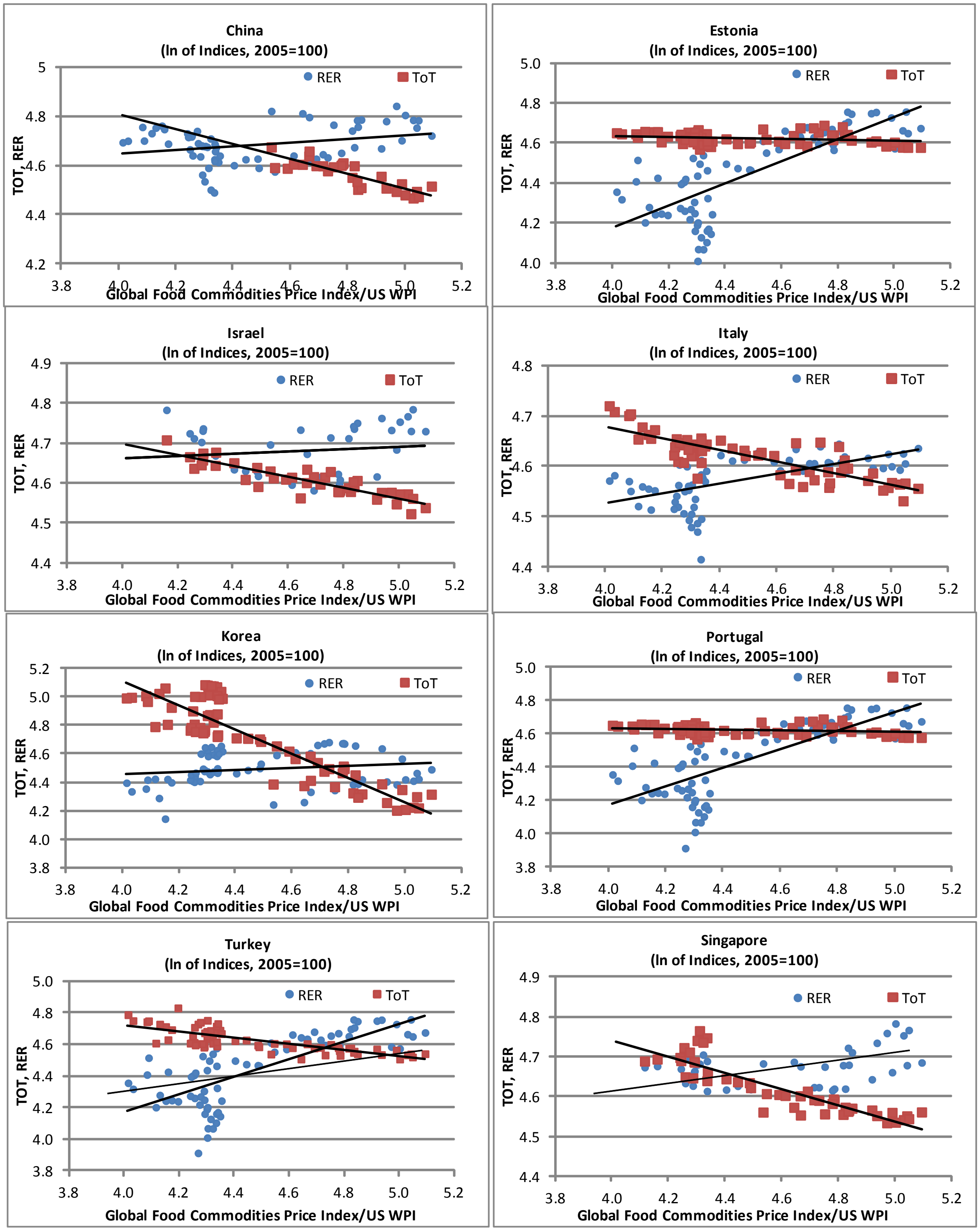
Figure 1. World WPI and World Food Price Index
(in deviations from HP-trend)



Sources: IMF and authors' calculations.

Figure 2. Covariance Between the Terms of Trade and the Real Effective Exchange Rate With World Food Prices



Sources: IMF and authors' calculations.

Figure 3a. Effects of a food price shock on natural output and natural TOT under Complete Markets

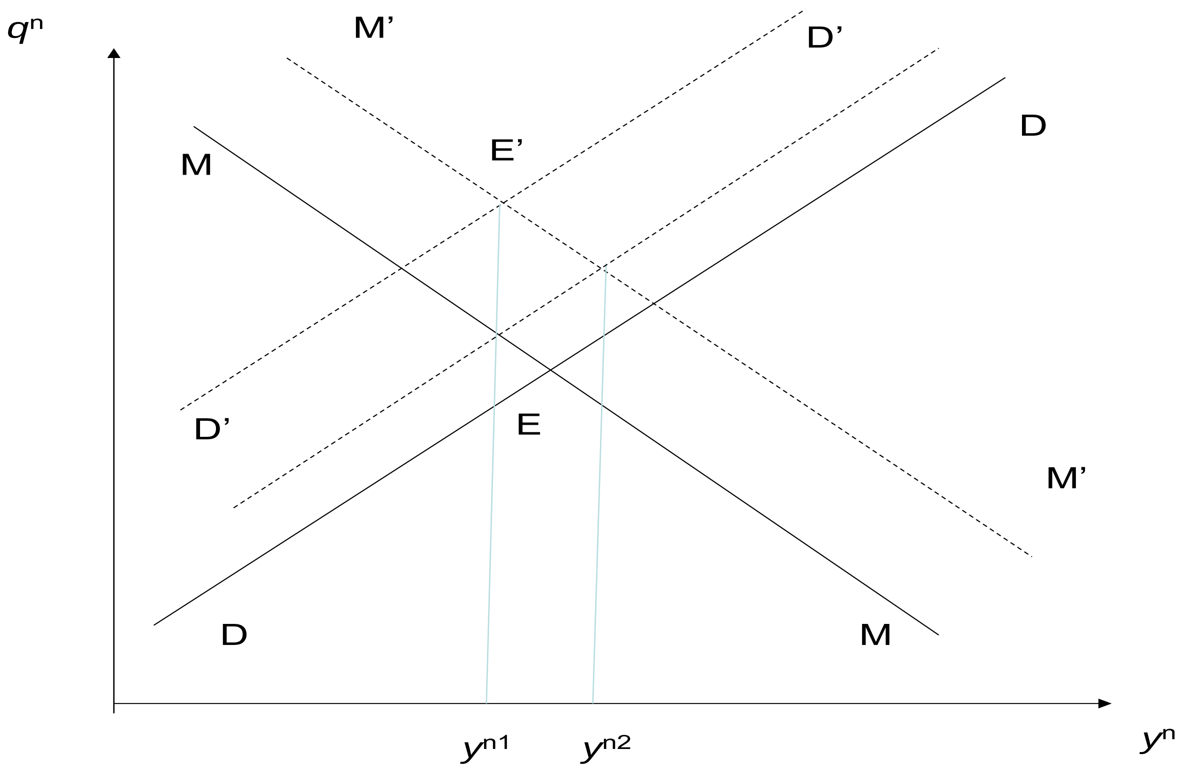


Figure 3b. Effects of a food price shock on natural output and natural TOT in Financial Autarky

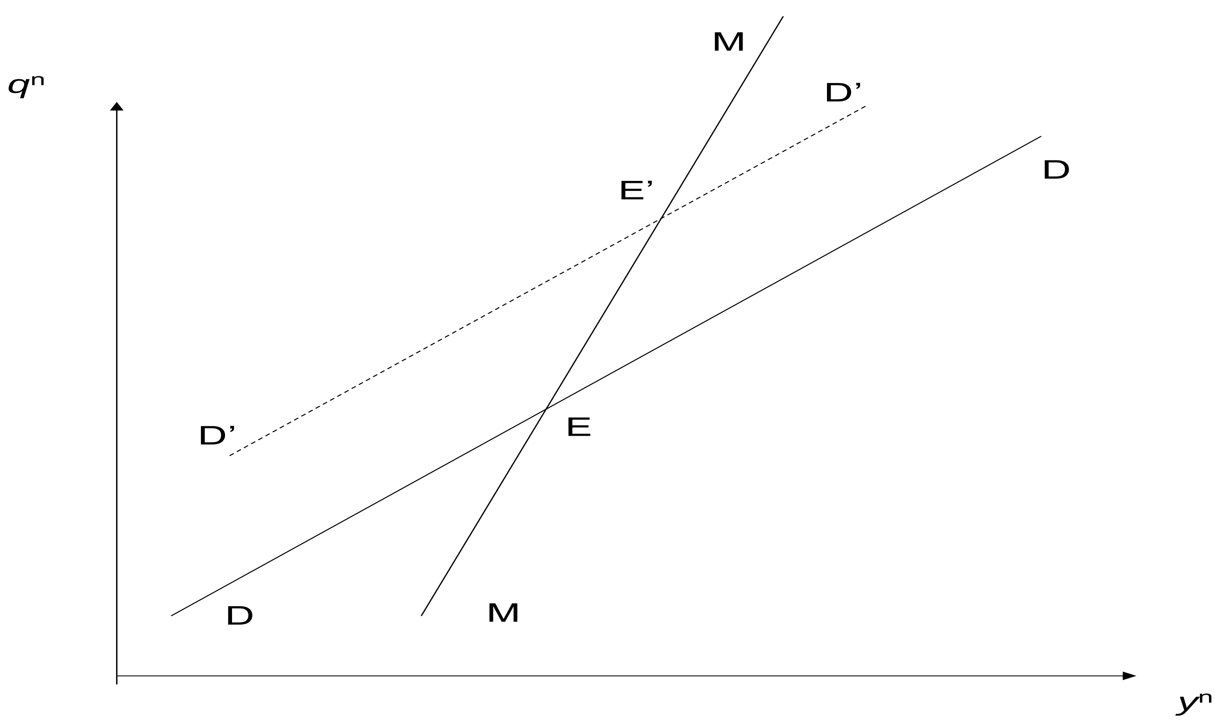


Figure 4a. Impulse-Responses to a Standard Deviation of z* Shocks under Complete Markets and *PPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

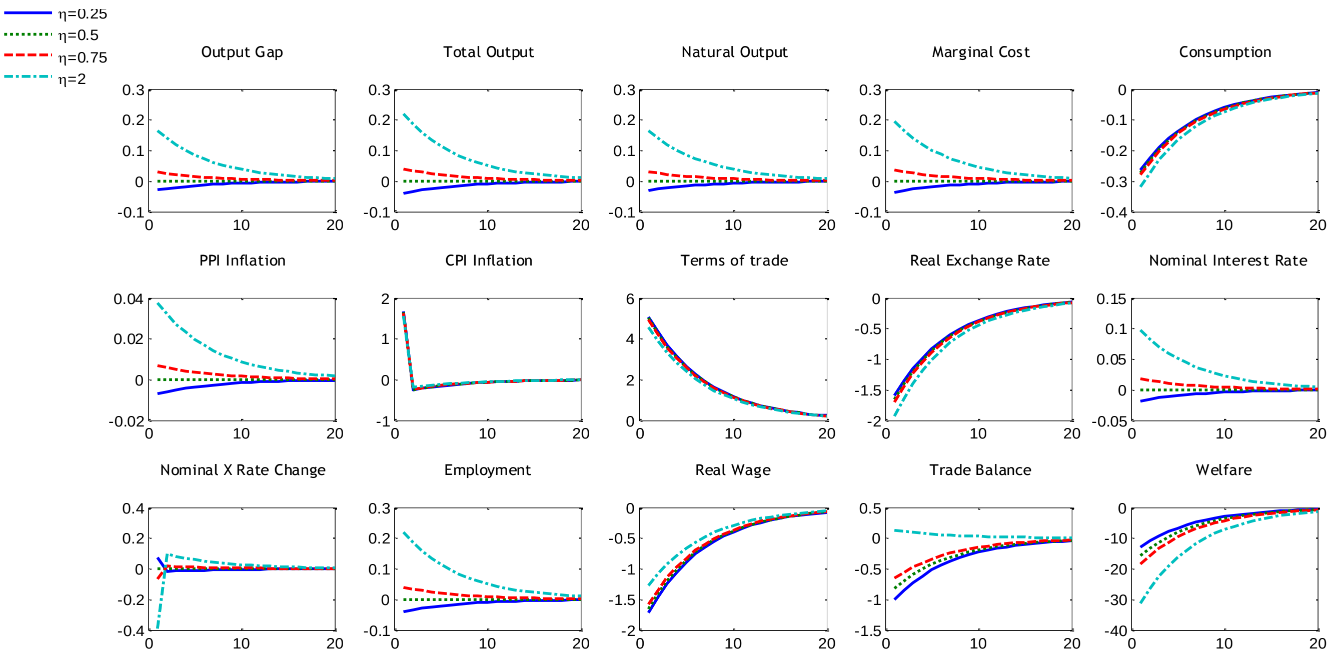


Figure 4b. Impulse-Responses to a Standard Deviation of z* Shocks under Complete Markets and *Headline CPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

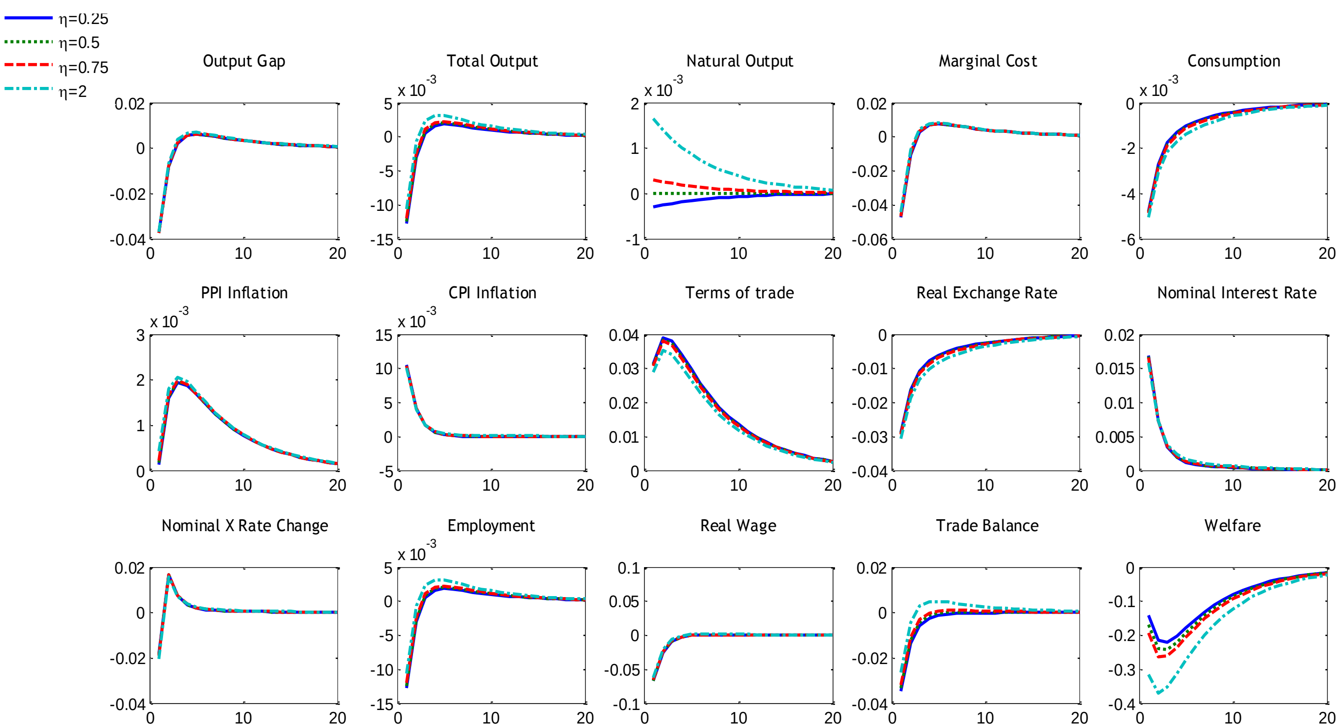


Figure 4c. Impulse-Responses to a Standard Deviation of z* Shocks under Complete Markets and *Expected CPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

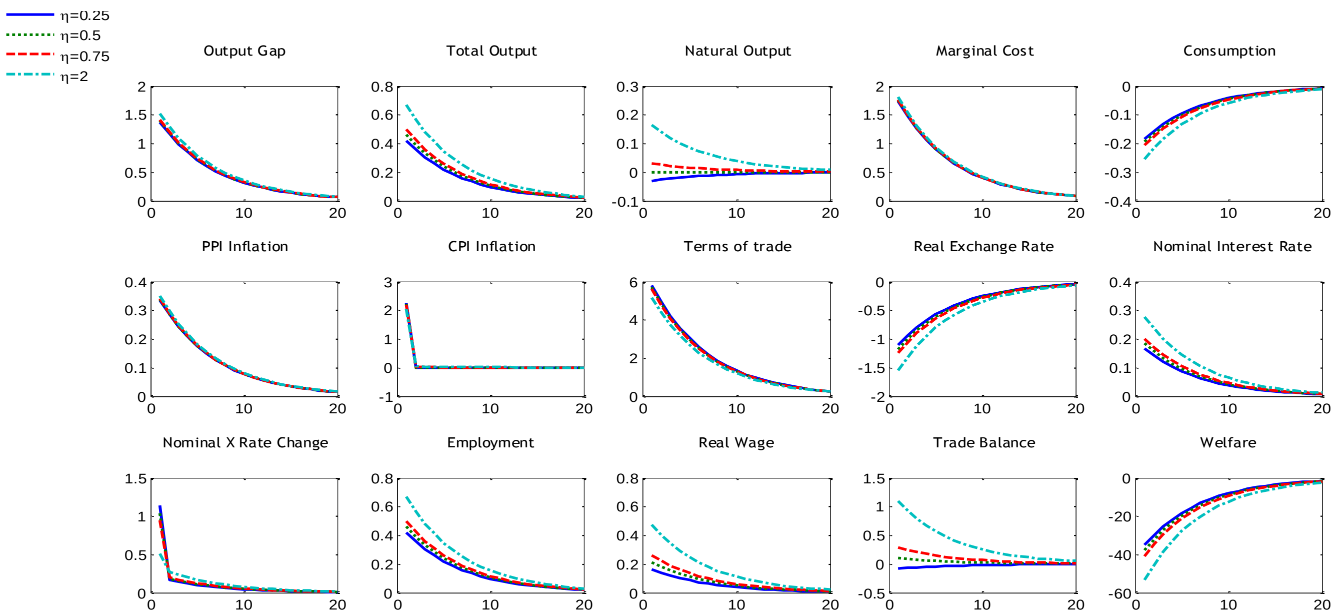


Figure 4d. Impulse-Responses to a Standard Deviation of z* Shocks under Complete Markets and an *Exchange Rate Peg* for Baseline Calibration and σ=2 (all values in percentage points)

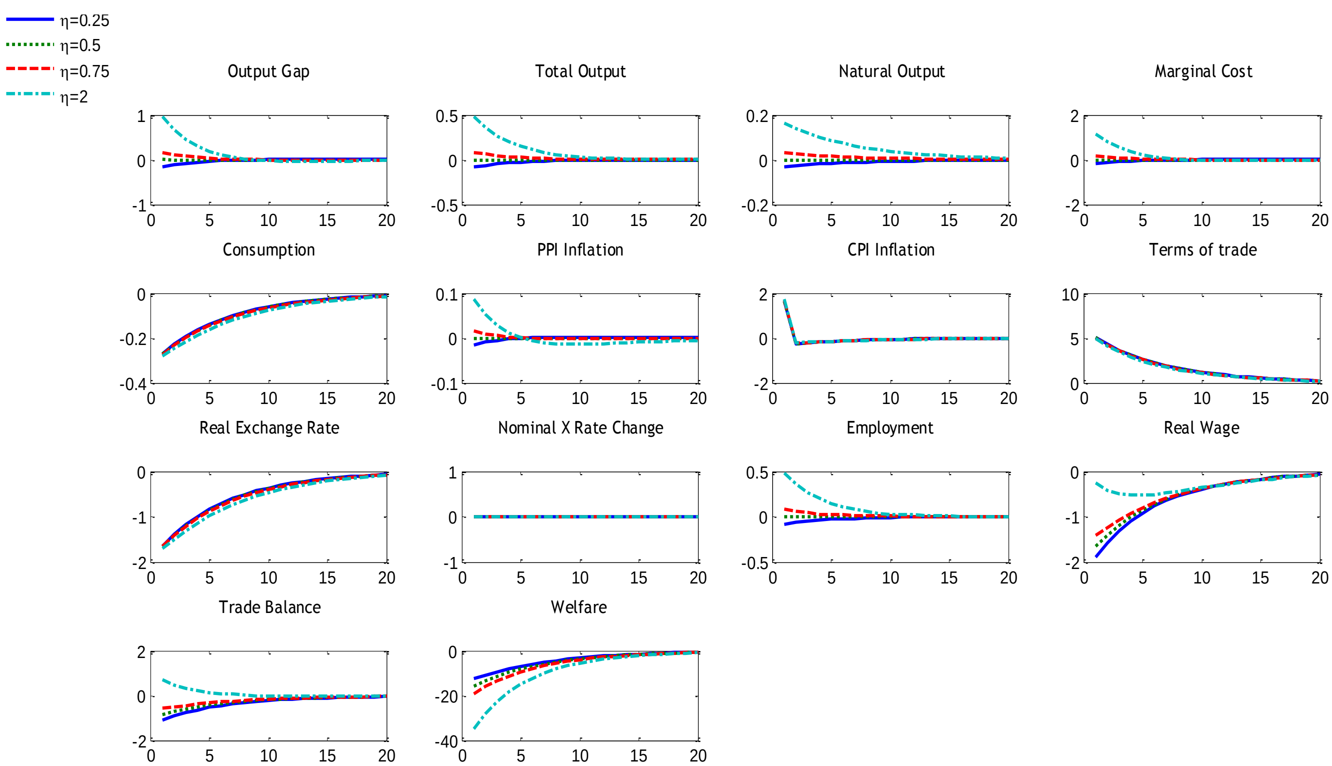


Figure 5a. Impulse-Responses to a Standard Deviation of z* Shocks under Financial Autarky and *PPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

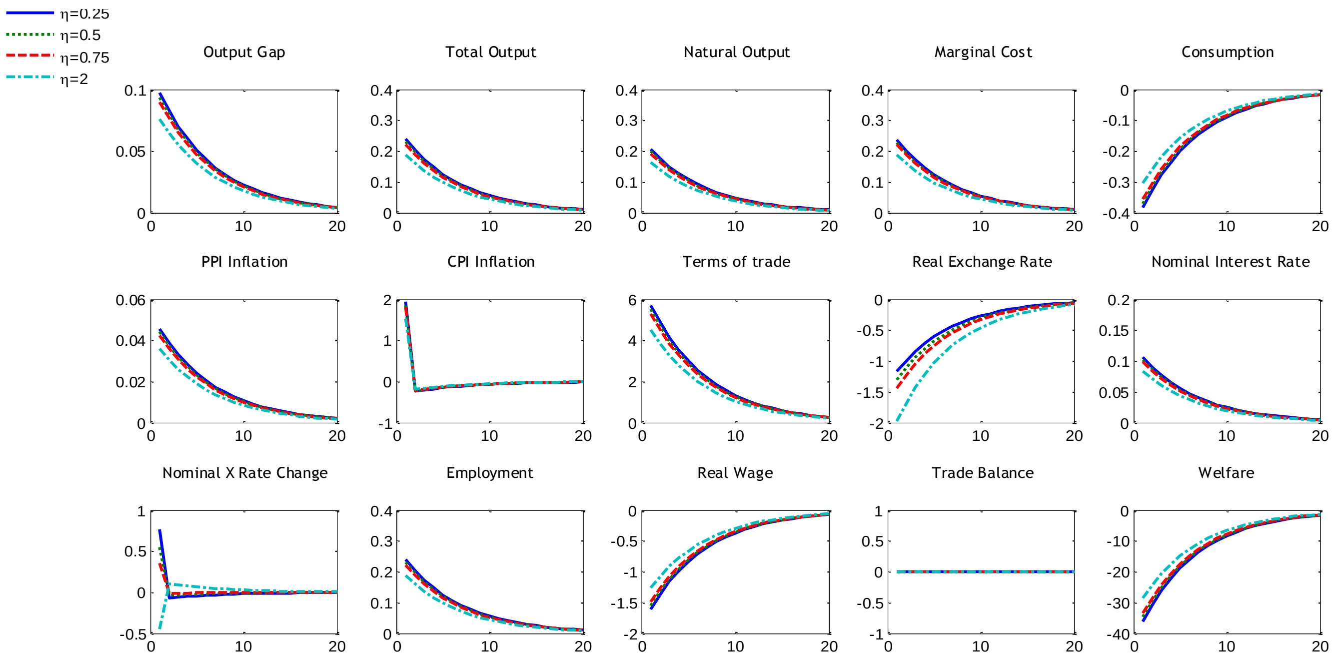


Figure 5b. Impulse-Responses to a Standard Deviation of z* Shocks under Financial Autarky and *CPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

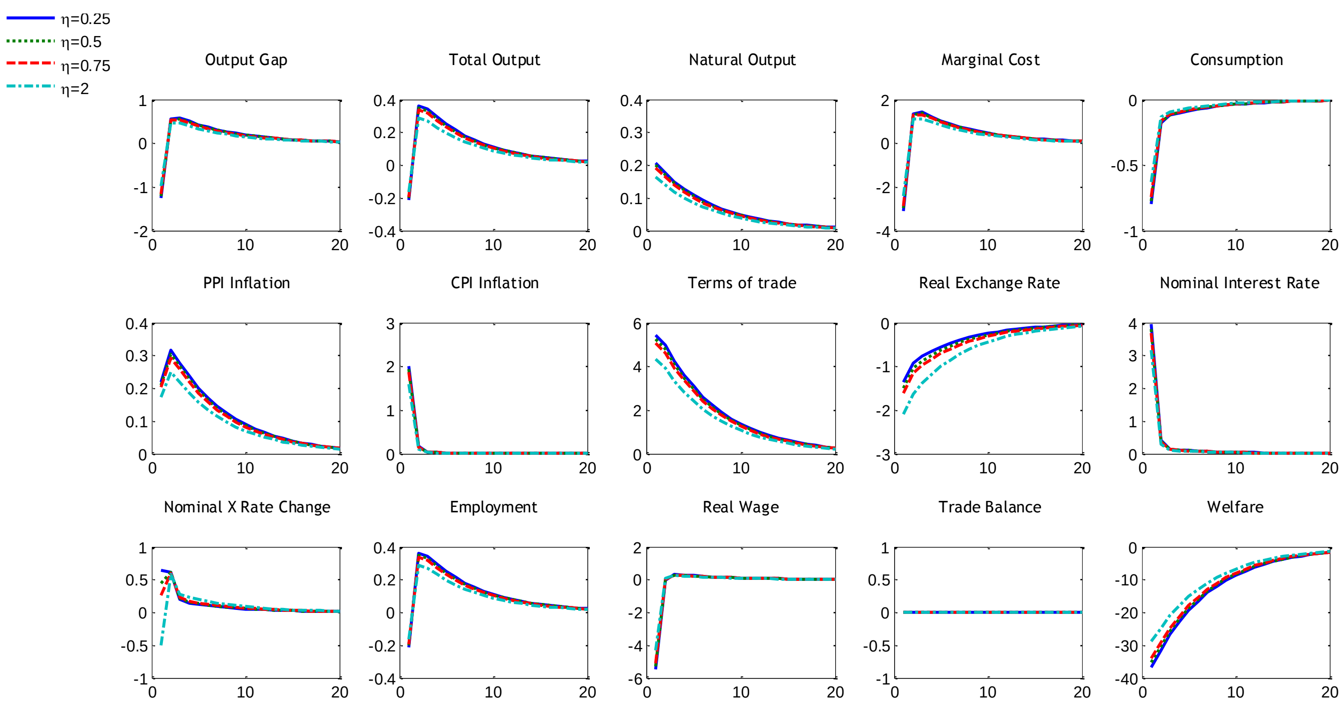


Figure 5c. Impulse-Responses to a Standard Deviation of z* Shocks under Financial Autarky and *Expected CPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

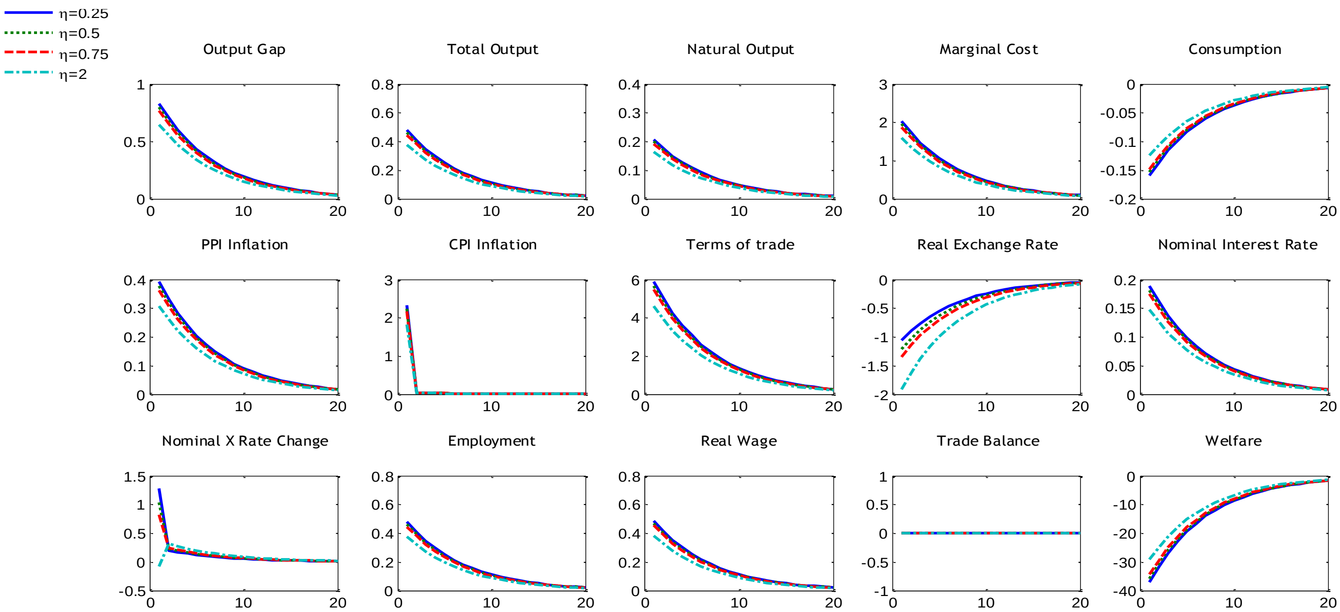


Figure 5d. Impulse-Responses to a Standard Deviation of z* Shocks under Financial Autarky and *Expected CPI Targeting* for Baseline Calibration and σ=2 (all values in percentage points)

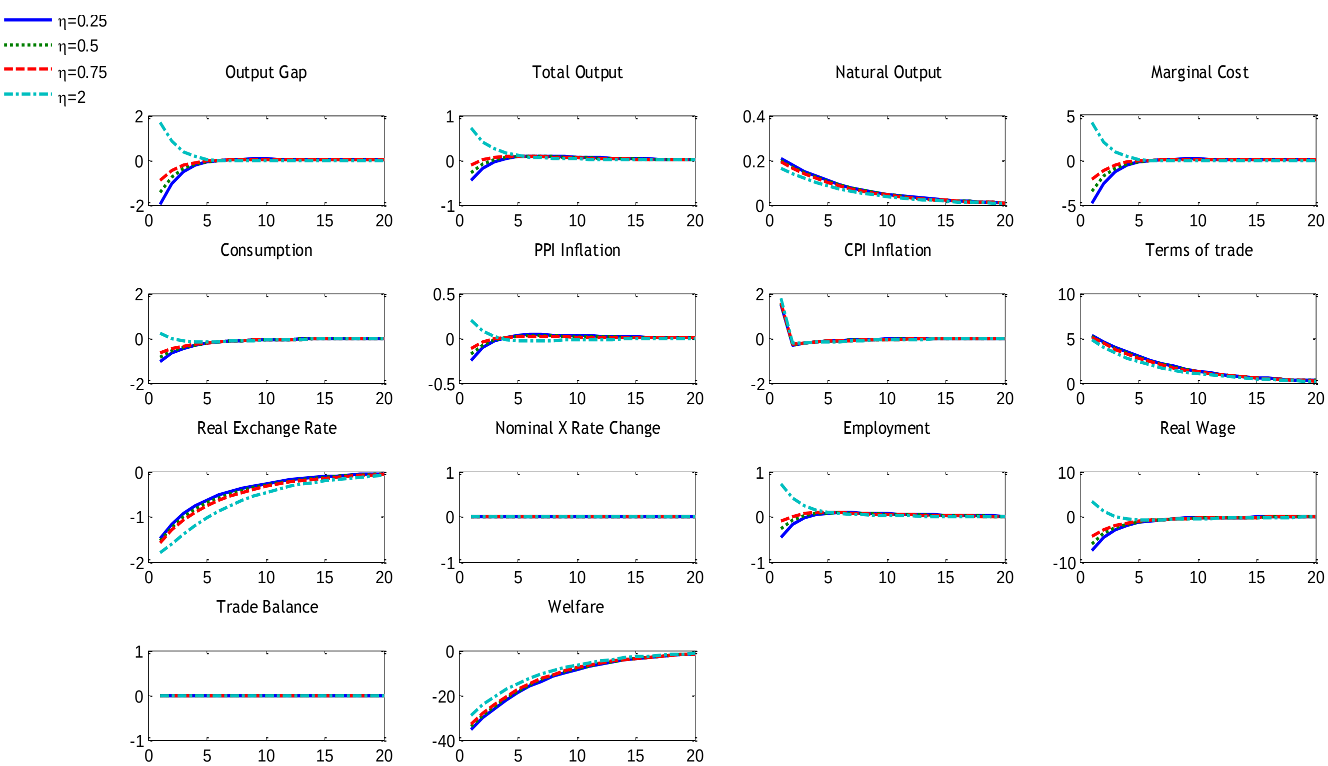


Table 1. Food Expenditure Shares in National Consumption Baskets

Austria	16%	Latvia	40%
Belgium	16%	Lithuania	45%
Bulgaria	43%	Luxemburg	14%
Chile	19%	Malta	34%
Cyprus	26%	Mexico	33%
Czech Republic	24%	Netherlands	12%
Denmark	14%	Panama	35%
Estonia	31%	Poland	30%
Finland	16%	Portugal	22%
France	15%	Romania	59%
Germany	16%	Slovakia	33%
Greece	21%	Slovenia	23%
Hungary	29%	Spain	25%
Ireland	18%	Sweden	12%
Italy	28%	UK	13%
Overall Median	**24%**	**EM Median**	**33%**
Overall Mean	**25%**	**EM Mean**	**34%**

Source: Rigobón (2008) and authors' calculations.

Table 2: Model Calibration

Discount Factor	β	0.99
Coefficient of risk aversion	σ	[1,6]
Inverse of elasticity of labor supply	φ	0,1
Degree of Openness	α	0.33
Average period between price adjustments	θ	[0.4,0.66]
Coefficient on inflation in Taylor Rule	ϕ_π	[1.5,2.5]
Coefficient on output gap in Taylor Rule	ϕ_y	[0,0.125]
Persistence parameter associated with productivity shocks	ρ_a	0.7
Persistence parameter associated with monetary policy shocks	ρ_v	0.6
Persistence parameter associated with import price shocks	ρ_z	0.85
Elasticity of substitution between varieties produced within any given country	ε	6
Elasticity of substitution between domestic and foreign goods	η	[0.25,4]
Ratio of initial home to foreign consumption	κ	1
Price Elasticity of Foreign Demand for the home goods	γ	[1,5]
Standard Deviation associated with monetary policy shock	σ_v	0.006
Standard Deviation associated with relative import price shock	σ_z	[0,0.05]
Standard Deviation associated with productivity shock	σ_a	0.012

Table 3. Welfare Gaps: Complete Markets with All Baseline Shocks and Strict Inflation Targeting
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.1039	0.0874	0.0527	-0.0159	-0.1462
2	-0.0194	-0.0333	-0.0615	-0.1145	-0.2091
4	-0.0439	-0.053	-0.0714	-0.1051	-0.1634
6	-0.0397	-0.0464	-0.0598	-0.0843	-0.1262

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	-0.0578	-0.0457	-0.0213	0.0221	0.0777
2	0.0263	0.0368	0.0573	0.0927	0.1386
4	0.0402	0.0472	0.0609	0.0843	0.115
6	0.0351	0.0403	0.0504	0.0677	0.0904

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.1369	0.1008	0.0212	-0.1522	-0.5504
2	-0.0416	-0.0696	-0.13	-0.2572	-0.5394
4	-0.0696	-0.0875	-0.1258	-0.2056	-0.3805
6	-0.0608	-0.0739	-0.1018	-0.1596	-0.286

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.046	0.0416	0.0314	0.0062	-0.0687
2	0.0069	0.0035	-0.0042	-0.0219	-0.0708
4	-0.0037	-0.0059	-0.0105	-0.0208	-0.0486
6	-0.0046	-0.0061	-0.0094	-0.0167	-0.036

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.2409	0.1883	0.0739	-0.1681	-0.6958
2	-0.061	-0.1028	-0.1913	-0.3714	-0.7473
4	-0.1135	-0.1405	-0.1971	-0.3105	-0.5432
6	-0.1005	-0.1202	-0.1615	-0.2438	-0.4119

PEG-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.1949	0.1466	0.0425	-0.1743	-0.6276
2	-0.0679	-0.1063	-0.1872	-0.3496	-0.677
4	-0.1097	-0.1346	-0.1866	-0.2897	-0.4949
6	-0.0959	-0.1141	-0.1521	-0.2272	-0.3761

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	EXP(CPI)	EXP(CPI)
2	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)
4	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)
6	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)

Table 4. Welfare Gaps: Complete Markets with Trivial Food Price Volatility and Strict Inflation Targeting
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.0036	0.0032	0.0024	0.0007	-0.0025
2	0.0011	0.0008	0.0002	-0.001	-0.0034
4	0.0003	0.0001	-0.0003	-0.001	-0.0025
6	0.0001	0	-0.0003	-0.0008	-0.0019

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.0444	0.0393	0.0291	0.0095	-0.0287
2	0.0061	0.0027	-0.0041	-0.017	-0.0419
4	-0.004	-0.006	-0.0101	-0.0177	-0.0324
6	-0.0048	-0.0062	-0.009	-0.0144	-0.0249

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0466	0.0421	0.0322	0.0111	-0.0393
2	0.012	0.0088	0.002	-0.0124	-0.0461
4	0.0013	-0.0006	-0.0047	-0.0134	-0.0334
6	-0.0005	-0.0018	-0.0048	-0.0109	-0.0252

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.048	0.0425	0.0314	0.0102	-0.0313
2	0.0072	0.0035	-0.0039	-0.018	-0.0453
4	-0.0037	-0.0059	-0.0103	-0.0187	-0.0349
6	-0.0046	-0.0062	-0.0093	-0.0153	-0.0268

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0502	0.0453	0.0346	0.0118	-0.0419
2	0.013	0.0096	0.0022	-0.0134	-0.0495
4	0.0016	-0.0005	-0.005	-0.0144	-0.0359
6	-0.0004	-0.0019	-0.0051	-0.0118	-0.0271

PEG-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0022	0.0027	0.0031	0.0016	-0.0106
2	0.0059	0.0061	0.0061	0.0046	-0.0042
4	0.0053	0.0054	0.0053	0.0043	-0.0011
6	0.0043	0.0043	0.0043	0.0035	-0.0003

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	PPI	EXP(CPI)
2	PPI	PPI	PEG	PEG	EXP(CPI)
4	PEG	PEG	PEG	PEG	EXP(CPI)
6	PEG	PEG	PEG	PEG	EXP(CPI)

Table 5. Welfare Gaps: Complete Markets with All Baseline Shocks and Flexible Inflation Targeting
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.068	0.063	0.0532	0.0354	0.0037
2	0.0121	0.0081	0.0002	-0.0137	-0.0372
4	-0.0054	-0.008	-0.013	-0.0218	-0.0362
6	-0.0072	-0.009	-0.0127	-0.0191	-0.0293

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	-0.0201	-0.0195	-0.0211	-0.0362	-0.1225
2	-0.0087	-0.0086	-0.0105	-0.0236	-0.0896
4	-0.0022	-0.0023	-0.0038	-0.0126	-0.0546
6	-0.0007	-0.0007	-0.0019	-0.0085	-0.039

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0364	0.0216	-0.0079	-0.0622	-0.155
2	-0.0089	-0.018	-0.0359	-0.0675	-0.1186
4	-0.0163	-0.0214	-0.0311	-0.048	-0.0747
6	-0.0144	-0.0178	-0.0245	-0.0361	-0.0541

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.0479	0.0435	0.0321	-0.0009	-0.1188
2	0.0034	-0.0005	-0.0103	-0.0373	-0.1268
4	-0.0076	-0.0102	-0.0168	-0.0344	-0.0908
6	-0.0078	-0.0098	-0.0146	-0.0275	-0.0683

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.125	0.1001	0.0526	-0.0272	-0.1449
2	0.0098	-0.0055	-0.034	-0.0799	-0.1431
4	-0.0199	-0.0283	-0.0438	-0.068	-0.0998
6	-0.0207	-0.0265	-0.0371	-0.0535	-0.0746

PEG-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0565	0.0412	0.0132	-0.026	-0.0325
2	-0.0002	-0.0094	-0.0254	-0.0439	-0.029
4	-0.0141	-0.0191	-0.0274	-0.0354	-0.0201
6	-0.0137	-0.0171	-0.0226	-0.0276	-0.0151

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	EXP(CPI)	EXP(CPI)
2	PPI	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)
4	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)
6	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)	EXP(CPI)

Table 6. Model statistics Under Simulated Random Shocks
(with σ=2; η=0.5; γ=5 and other baseline calibration for shocks)

	Complete Markets						Financial Autarky					
	Ramsey Allocation	Natural Allocation	PPI Rule	CPI Rule	EXP(CPI) Rule	PEG Rule	Ramsey Allocation	Natural Allocation	PPI Rule	CPI Rule	EXP(CPI) Rule	PEG Rule
Standard deviations (in %)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Domestic Output	0.159	0.7515	0.6551	1.3199	1.3436	1.0467	0.6587	0.5403	0.4935	0.7696	0.9187	1.4334
Employment	0.201	0.1865	0.4219	0.7515	1.2099	1.0865	0.3871	0.4185	0.6044	0.8595	1.0135	1.4624
Consumption	0.4224	0.5322	0.5285	0.5966	0.4075	0.5462	1.2361	0.8371	0.7338	0.7334	0.3424	1.7561
Real Exchange Rate	2.293	3.2252	3.2031	4.8379	2.4696	3.3101	2.7369	2.5166	2.4875	2.4315	2.2887	2.7642
Home Good Price/CPI	3.1116	3.155	3.1496	3.0891	3.6094	3.1763	3.4131	3.4392	2.5836	2.5314	2.908	2.8576
Domestic Inflation		0	0.1263	0.51	0.6648	0.4725		0	0.1911	0.6836	0.7673	0.7126
Means in % of SS deviation												
Domestic Output	0.0008	0.0118	-0.0048	-0.1437	-0.2317	-0.132	0.0111	0.0109	-0.0037	-0.1128	-0.1501	-0.1211
Employment	0.0012	0.0038	-0.0077	-0.1319	-0.2118	-0.1181	0.0078	0.0092	0.0002	-0.0841	-0.1141	-0.0912
Consumption	-0.0045	-0.0051	-0.0072	-0.0364	-0.0573	-0.0322	-0.0006	-0.0024	-0.018	-0.1246	-0.17	-0.113
Real Exchange Rate	-0.0078	-0.0051	-0.0182	-0.1877	-0.3323	-0.1677	-0.0282	-0.0298	-0.0371	-0.0895	-0.1132	-0.0896
Home Good Price/CPI	-0.0068	0.0025	0.0087	0.1001	0.1451	0.0836	0.0019	-0.0002	0.0028	0.0274	0.0362	0.0338
Domestic Inflation		0	0.0031	0.0855	0.0475	0.0011		0	0.0011	0.0708	0.0176	0.0025
Consumption/Output ratio	**99.984**	**99.949**	**99.993**	**100.634**	**101.027**	**100.580**	**99.934**	**99.929**	**99.926**	**99.934**	**99.848**	**100.025**

Table 7. Welfare Gaps: Incomplete Markets (ψ=0.9) with All Baseline Shocks and Full-Fledge Inflation Targeting
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.0922	0.0892	0.083	0.0708	0.0468
2	0.0379	0.0361	0.0323	0.0249	0.0106
4	0.0184	0.0181	0.0172	0.0151	0.0103
6	0.014	0.0143	0.0149	0.0153	0.0148

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	-0.0203	-0.0206	-0.0231	-0.0361	-0.0994
2	-0.0108	-0.0113	-0.0139	-0.0248	-0.0712
4	-0.0038	-0.0044	-0.0066	-0.0141	-0.0423
6	-0.0012	-0.0019	-0.0038	-0.0099	-0.0307

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0483	0.0348	0.009	-0.0344	-0.0982
2	0.011	0.003	-0.0117	-0.0349	-0.066
4	0.0096	0.0053	-0.0026	-0.0147	-0.0299
6	0.0143	0.0111	0.0055	-0.003	-0.0138

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.0719	0.0685	0.0598	0.0347	-0.0527
2	0.0271	0.0248	0.0184	0	-0.0606
4	0.0146	0.0137	0.0106	0.001	-0.032
6	0.0128	0.0125	0.011	0.0054	-0.0159

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.1405	0.124	0.092	0.0364	-0.0515
2	0.0489	0.0391	0.0206	-0.0101	-0.0554
4	0.0281	0.0233	0.0146	0.0004	-0.0196
6	0.0282	0.0255	0.0204	0.0123	0.001

EPT-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0686	0.0554	0.0321	0.0017	0.0012
2	0.0218	0.0143	0.0022	-0.0101	0.0052
4	0.0134	0.0097	0.0039	-0.0005	0.0124
6	0.0154	0.013	0.0094	0.007	0.0169

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	PPI	PEG
2	PPI	PPI	PPI	EXP(CPI)	PEG
4	PPI	PPI	PPI	PPI	PEG
6	PPI	PPI	PPI	PPI	PEG

Table 8. Welfare Gaps: Incomplete Markets (ψ=0.9) with All Baseline Shocks
Full Fledge Inflation Targeting and Unitary Export Price Elasticity
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.2378	0.2397	0.2359	0.2138	0.1527
2	0.14	0.1402	0.1351	0.1159	0.0733
4	0.0728	0.0741	0.0728	0.0639	0.0433
6	0.047	0.0493	0.0507	0.0475	0.0371

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	-0.0684	-0.0776	-0.0853	-0.0836	-0.0967
2	-0.0585	-0.0617	-0.0624	-0.0573	-0.0686
4	-0.0334	-0.0357	-0.0368	-0.0355	-0.0451
6	-0.0212	-0.0238	-0.0262	-0.0275	-0.0366

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.192	0.184	0.1591	0.0989	-0.0043
2	0.113	0.1036	0.082	0.0414	-0.0159
4	0.063	0.0563	0.0424	0.0194	-0.0091
6	0.0453	0.0402	0.0302	0.0143	-0.0043

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.1692	0.162	0.1505	0.13	0.0559
2	0.0814	0.0784	0.0726	0.0586	0.0046
4	0.0394	0.0384	0.0359	0.0284	-0.0019
6	0.0258	0.0255	0.0245	0.02	0.0004

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.4303	0.4241	0.3954	0.3129	0.1484
2	0.2532	0.244	0.2173	0.1574	0.0574
4	0.1358	0.1304	0.1152	0.0833	0.0342
6	0.0924	0.0896	0.0809	0.0619	0.0327

PEG-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.2606	0.2617	0.2446	0.1827	0.0925
2	0.1717	0.1654	0.1445	0.0988	0.0528
4	0.0964	0.092	0.0793	0.0549	0.0361
6	0.0665	0.064	0.0564	0.0418	0.0323

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	PPI	PPI
2	PPI	PPI	PPI	PPI	PPI
4	PPI	PPI	PPI	PPI	PEG
6	PPI	PPI	PPI	PPI	PPI

Table 9. Welfare Gaps: Incomplete Markets (ψ=0.9) with All Baseline Shocks
Flexible IT, Unitary Export Price Elasticity, and Fully Elastic Labor
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.0777	0.0725	0.0642	0.0547	0.0534
2	0.0333	0.0316	0.029	0.0265	0.0252
4	0.0138	0.0137	0.0137	0.0138	0.013
6	0.0078	0.0082	0.0089	0.0099	0.0098

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	-0.0265	-0.0239	-0.0207	-0.023	-0.0641
2	-0.0116	-0.011	-0.0107	-0.014	-0.0379
4	-0.0039	-0.0042	-0.005	-0.0079	-0.0207
6	-0.0013	-0.0019	-0.0031	-0.0058	-0.0143

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0665	0.0627	0.0498	0.0097	-0.1064
2	0.0338	0.0308	0.0223	0.0001	-0.0504
4	0.0179	0.0161	0.0113	0.0009	-0.0169
6	0.0127	0.0113	0.0081	0.0017	-0.0071

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.0512	0.0487	0.0435	0.0317	-0.0107
2	0.0217	0.0206	0.0183	0.0125	-0.0127
4	0.0099	0.0095	0.0086	0.0059	-0.0077
6	0.0065	0.0063	0.0059	0.0041	-0.0045

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.1442	0.1353	0.1141	0.0645	-0.053
2	0.0672	0.0624	0.0514	0.0266	-0.0253
4	0.0317	0.0298	0.025	0.0147	-0.0039
6	0.0205	0.0195	0.017	0.0116	0.0027

PEG-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.093	0.0866	0.0705	0.0328	-0.0423
2	0.0455	0.0418	0.033	0.0141	-0.0125
4	0.0218	0.0203	0.0163	0.0088	0.0038
6	0.014	0.0133	0.0112	0.0075	0.0072

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	PPI	EXP(CPI)
2	PPI	PPI	PPI	PPI	EXP(CPI)
4	PPI	PPI	PPI	PPI	PEG
6	PPI	PPI	PPI	PPI	PEG

Table 10. Welfare Gaps: Incomplete Markets (ψ=0.9) with All Baseline Shocks
Flexible IT, Unitary Export Price Elasticity, Fully Elastic Labor and Lower Price Stickiness
(in % of Steady State Consumption)

PPI-CPI

sigma\eta	0.25	0.5	1	2	4
1	0.0337	0.031	0.0275	0.0263	0.0394
2	0.0146	0.0136	0.0126	0.0129	0.0177
4	0.0065	0.0063	0.0061	0.0065	0.0075
6	0.0041	0.0041	0.0041	0.0045	0.0047

CPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	-0.0067	-0.0057	-0.0052	-0.0102	-0.0418
2	-0.0031	-0.0029	-0.0032	-0.0065	-0.0222
4	-0.0012	-0.0013	-0.0017	-0.0035	-0.0102
6	-0.0005	-0.0007	-0.0012	-0.0024	-0.006

CPI-Exp(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0234	0.0225	0.0182	0.0023	-0.0492
2	0.0114	0.0106	0.0077	-0.0008	-0.0222
4	0.0056	0.0052	0.0037	0	-0.0069
6	0.0038	0.0035	0.0025	0.0005	-0.0025

PPI-PEG

sigma\eta	0.25	0.5	1	2	4
1	0.027	0.0253	0.0222	0.0161	-0.0024
2	0.0115	0.0107	0.0093	0.0064	-0.0046
4	0.0054	0.005	0.0044	0.003	-0.0027
6	0.0037	0.0034	0.003	0.0021	-0.0013

PPI-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0571	0.0536	0.0457	0.0286	-0.0098
2	0.026	0.0242	0.0203	0.0121	-0.0045
4	0.0122	0.0114	0.0098	0.0065	0.0006
6	0.0079	0.0075	0.0067	0.005	0.0022

PEG-EXP(CPI)

sigma\eta	0.25	0.5	1	2	4
1	0.0301	0.0282	0.0235	0.0125	-0.0074
2	0.0145	0.0135	0.011	0.0057	0
4	0.0068	0.0064	0.0054	0.0035	0.0033
6	0.0042	0.0041	0.0037	0.0029	0.0034

Ranking matrix

sigma\eta	0.25	0.5	1	2	4
1	PPI	PPI	PPI	PPI	EXP(CPI)
2	PPI	PPI	PPI	PPI	EXP(CPI)
4	PPI	PPI	PPI	PPI	PEG
6	PPI	PPI	PPI	PPI	PEG