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Abstract

This paper analyses the importance of real wage rigidities, in particular through their interaction with price stickiness, for optimal monetary policy in a calibrated small open economy DSGE model including oil in production and consumption. Blanchard and Galí (2007a) show real rigidities to introduce a trade-off between stabilising inflation and the welfare-relevant output gap. The present paper complements their findings by showing that the welfare cost of real rigidities can be substantial compared to nominal frictions. In a typical "tale of the second best", we also show that in the presence of real wage rigidities, price stickiness can be welfare-enhancing.

Keywords: DSGE model, price stickiness, real wage rigidity, oil price shocks

JEL classification: E30, F41, Q43

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1. Introduction

After having been largely ignored by monetary economists for most of the past decade, the importance of real rigidities for monetary policy has received fresh impetus with a recent paper by Blanchard and Galí (2007a) showing that such rigidities introduce a trade-off between stabilising inflation or the welfare-relevant output gap. The welfare consequences of this monetary policy dilemma have not been explored, however. One interesting question in this regard is whether the magnitude of real rigidities that is likely to be encountered in practice entails significant welfare losses, compared with those from typical degrees of price stickiness. Also, the potential importance of real rigidities for monetary policy raises the question of whether and how they interact with nominal frictions.

This paper addresses these issues through a new-Keynesian small open economy model incorporating one major type of real rigidity, namely real wage rigidity (as in Blanchard and Galí 2007a), in the presence of one particular type of cost-push shock, namely an oil price shock. Real and nominal rigidity parameters are calibrated within the range of values found in recent empirical analyses for euro area countries and the US. The focus on oil price shocks as the exogenous disturbance has particular empirical appeal because such shocks are relatively frequent, can be large and are easy to observe – which reduces the need for policy makers to consider proxy measures such as the output gap for shock identification. Incidentally, in another recent paper, Blanchard and Galí (2007b) find that lower real wage rigidity has been a major factor behind the benign macroeconomic effects of the oil price shocks of the 2000s, compared with those of the 1970s.

Oil price disturbances have direct effects on both supply and demand in our framework. On the supply side, higher oil prices raise production costs. On the demand side, they reduce real wages and household wealth. Lower purchasing power together with real wage persistence push nominal wage claims up and feed back into higher production costs. At the same time, consumption declines, although households are assumed to partly substitute non-oil for oil goods. As a result, the central bank is faced with both a decline in aggregate demand and higher inflation.

We assume the central bank to implement the optimal Ramsey solution, i.e. the optimal commitment strategy for given exogenous shock and economic features. The optimal commitment achieves the best possible stabilisation result and constitutes the policy loss frontier. This assumption also allows a clearer focus on the interaction between rigidities in defining the welfare frontier. Indeed, under the alternative policy framework of simple interest rate rules, the policy rule itself might affect the interaction between nominal and real rigidities.

The paper presents impulse responses to persistent oil price shocks and examines the welfare consequences of rigidities for a small open economy that is price-taker in both oil and non-oil goods markets. The main findings are two-fold. First, under oil price shocks, real wage rigidities imply substantial welfare losses, much larger in fact than those from nominal rigidities. Second, for a given degree of real wage rigidity, welfare losses *decrease* in the degree of nominal rigidity. Nominal frictions dampen the initial inflation and wage reactions to exogenous shocks and the magnitude of second round effects. This suggests that price rigidity may be second best under real wage inertia. By contrast, reducing real wage inertia is always welfare-enhancing regardless of the degree of price stickiness.

The remainder of this paper proceeds as follows. Section 2 outlines the new-Keynesian open economy framework. Section 3 briefly sketches the notion of optimal Ramsey policy. Section 4 discusses the scenarios to simulate and the parameter calibration. Section 5 presents and discusses the numerical results. Section 6 summarises the main findings and concludes.

2. The open economy model

The open economy model with oil as production input and consumption good borrows from previous contributions. The open economy framework builds on Galí and Monacelli (2005), the inclusion of oil is a simplified version of De Fiore *et al.* (2006), and the introduction of real wage persistence adopts the shortcut used by Blanchard and Galí (2007a), Christoffel and Linzert (2005) and Faia (2007). Our model combines a small open economy block with a simple representation for the rest of the world. Consumers are forward-looking and not subject to liquidity constraints. In order to focus discussion, the model abstracts from fiscal policy in the form of both government expenditure and taxation.

2.1 The small open economy

2.1.1 Household sector

The representative household maximizes lifetime utility over an infinite planning horizon. Overall household welfare is the expected discounted value of the stream of period utility

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t \ . \tag{1}$$

Period utility U is additive in the utility of consumption C and the disutility of hours worked N

$$U_t = \ln C_t - \kappa \frac{N_t^{1+\varphi}}{1+\varphi}. \tag{2}$$

For simplicity we assume log consumption utility, which implies a unit intertemporal elasticity of substitution. The parameter κ quantifies the relative weight of leisure in the utility function, while φ^{-1} and β are the labour supply elasticity and the discount factor, respectively. The representative households is subject to the period budget constraint

$$W_t N_t + D_t = P_{C,t} C_t + E_t Q_{t,t+1} D_{t+1}, \tag{3}$$

where W_t is the nominal wage and D_t is the nominal revenue from the asset portfolio, including shares in firms. On the right-hand side, $P_{C,t}$ is the consumer price index (CPI), C_t is real consumption, $Q_{t,t+1}$ is the stochastic discount factor for one-period ahead nominal pay-offs, and D_{t+1} nominal pay-offs one period ahead. Households have access to a complete set of contingent claims, which is internationally traded

The household maximizes welfare (1) under the constraint (3), which provides the first-order condition for the optimal inter-temporal consumption

$$1 = \beta(1+i_t)E_t\left(\frac{C_t}{C_{t+1}}\frac{P_{C,t}}{P_{C,t+1}}\right), \tag{4}$$

where $1+i_t = 1/E_t Q_{t,t+1}$ is the gross return on a riskless one-period bond that pays off one unit of domestic currency one period ahead. Consequently, $E_t Q_{t,t+1}$ is the price of this bond.

The first-order condition for the optimal intra-temporal consumption-leisure choice is

$$\frac{\tilde{W}_t}{P_{C,t}} = \frac{\kappa N^{\varphi}}{C_t^{-1}}. \tag{5}$$

Due to persistence, actual real wages can however deviate from the optimal wage level in (5). Following Blanchard and Galí (2007a), Christoffel and Linzert (2005) and Faia (2007), we represent actual real wages as a weighted average of previous and optimal real wages

$$\frac{W_t}{P_{C,t}} = \left(\frac{W_{t-1}}{P_{C,t-1}}\right)^{\rho_w}\left(\frac{\tilde{W}_t}{P_{C,t}}\right)^{1-\rho_w}, \tag{6}$$

where $0 \le \rho_w \le 1$ indicates the degree of real persistence. Real wage persistence also introduces inertia in marginal production costs.[1]

[1] This introduction of real rigidity is a simplifying shortcut. It ignores that with real persistence wage setting may become a dynamic optimisation problem similar to the pricing decision of firms. However, Bodard *et al.* (2006) show that a search model of unemployment with staggered wage setting can provide a microfoundation of this simple representation of real wage inertia. Alternatively, equation (6) could also summarize some form of partial wage indexation (see Campolmi 2006). A real wage mark-up ν could be introduced in equation (5) to yield $\tilde{W}_t / P_{C,t} = \nu\kappa N_t^{\varphi} C_t$ and would constitute a further inefficiency in the model.

The household consumes a bundle of manufactured goods, M, and imported oil, O. Both components enter a CES consumption utility function

$$C_t = \left[(1-\gamma)^{\frac{1}{\varepsilon}} M_t^{\frac{\varepsilon-1}{\varepsilon}} + \gamma^{\frac{1}{\varepsilon}} O_t^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} . \tag{7}$$

The parameters γ and ε respectively quantify the steady-state share of oil in consumption and the substitution elasticity between oil and manufactured goods.

In a second stage, the household allocates its expenditure for manufactured goods on domestic production, M_H, and imported goods, M_F. Unit elasticity of substitution between domestic and imported manufactured goods is assumed for simplicity, which gives the Cobb-Douglass type utility function

$$M_t = \frac{M_{H,t}^{1-\alpha} M_{F,t}^{\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}} , \tag{8}$$

where the parameter $0 \leq \alpha \leq 1$ quantifies the equilibrium non-oil import share.

Maximising the consumption utility (7) and (8) for given prices of oil, P_O, non-oil consumer goods, P_M, domestic non-oil goods, P_H, and non-oil imports, P_F, gives the demand functions

$$M_t = (1-\gamma) \left(\frac{P_{M,t}}{P_{C,t}} \right)^{-\varepsilon} C_t \tag{9}$$

$$O_t = \gamma \left(\frac{P_{O,t}}{P_{C,t}} \right)^{-\varepsilon} C_t \tag{10}$$

$$M_{H,t} = (1-\alpha) \left(\frac{P_{H,t}}{P_{M,t}} \right)^{-1} M_t \tag{11}$$

For a more elaborate wage-setting model, where some households reset wages in a purely forward-looking manner while others index them to inflation in order to preserve real wage levels, see Rabanal (2001).

$$M_{F,t} = \alpha\left(\frac{P_{F,t}}{P_{M,t}}\right)^{-1} M_t \quad . \tag{12}$$

Inserting the equations (9) and (10) in (7) as well as (11) and (12) in (8) provides the CPI

$$P_{C,t} = \left[(1-\gamma)P_{M,t}^{1-\varepsilon} + \gamma P_{O,t}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{13}$$

and the non-oil consumer goods price index

$$P_{M,t} = P_{H,t}^{1-\alpha} P_{F,t}^{\alpha} \,, \tag{14}$$

which is the core price index in our model. The impact of import prices on the domestic CPI increases with the equilibrium shares of oil and non-oil imports.

2.1.2 Aggregate demand

Real output in the small country, i.e. its real GDP, is the sum of the internal demand for domestic goods, M_H, and export demand, M_H^*. As we neglect government expenditure and capital goods, real output equals

$$Y_t = M_{H,t} + M_{H,t}^* \quad . \tag{15}$$

The demand functions (11) and (30) determine M_H and M_H^*. Consequently, domestic output depends on the relative price of oil, determining the oil and non-oil shares in consumption, and the price of domestic relative to imported non-oil consumer goods. Demand for non-oil goods increases in the relative price of oil, while the strength of this substitution effect depends on the elasticity of substitution between oil and manufactured goods.

2.1.3 Aggregate supply

The model adopts a simple framework of the representative firm and aggregate supply. Each firm produces output with labour, N, and oil, O, as factor inputs and according to a CES production function

$$Y_{h,t} = A_t\left[(1-\theta)^{\frac{1}{\eta}} N_{h,t}^{\frac{\eta-1}{\eta}} + \theta^{\frac{1}{\eta}} O_{h,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{16}$$

with 0≤θ≤1 as the steady-state input share of oil and η as the elasticity of substitution between the two inputs. Technology is identical across all firms and exogenously given. For notational simplicity total factor productivity A_t can be set to one.[2]

Firms produce non-oil goods under monopolistic competition. Domestic output consists of differentiated varieties, each one produced by a single firm. The range of differentiated products has a mass of one. The demand for variety h equals

$$Y_{h,t} = \left(\frac{P_{h,t}}{P_{H,t}}\right)^{-\mu} Y_t \tag{17}$$

and depends on its relative price. The higher the elasticity of substitution between varieties in consumption, μ, the stronger the demand reaction to changes in the relative price of h.

Combining equations (16) and (17) together with the fact that in equilibrium all firms choose the same optimal input combination yields the aggregate production function

$$Y_t \int_0^1 \left(\frac{P_{h,t}}{P_{H,t}}\right)^{-\mu} dh = \left[(1-\theta)^{\frac{1}{\eta}} N_t^{\frac{\eta-1}{\eta}} + \theta^{\frac{1}{\eta}} O_t^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{18}$$

that relates output to factor demand. The price dispersion term on the left side of (18) accounts for the distortionary impact of price dispersion on consumption decisions and output.

[2] Atkeson and Kehoe (1999), Carlstrom and Fuerst (2006), De Fiore *et al.* (2006), Leduc and Sill (2006) and Roeger (2005) use production functions with three inputs - labour, capital and energy - and assume either Cobb-Douglass or CES functional forms. The Cobb-Douglass function assumes a unit elasticity of substitution between factor inputs.

The optimising firm chooses the cost-minimising factor mix, which depends on relative factor prices and relative factor productivity. Minimising the production costs $W_tN_{h,t}+P_{O,t}O_{h,t}$ under (16) yields

$$\frac{O_t}{N_t}=\frac{\theta}{1-\theta}\left(\frac{W_t}{P_{C,t}}\frac{P_{C,t}}{P_{O,t}}\right)^{\eta} \tag{19}$$

as the optimal factor mix of domestic producers for given relative input prices and

$$Y_{h,t}=(1-\theta)^{\frac{1}{\eta-1}}\left[1+\frac{\theta}{1-\theta}\left(\frac{W_t}{P_{C,t}}\frac{P_{C,t}}{P_{O,t}}\right)^{\eta-1}\right]^{\frac{\eta}{\eta-1}}N_{h,t} \tag{20}$$

as the cost minimising production at firm level in the absence of adjustment costs. Under constant returns to scale, identical production technology and cost minimisation, real marginal production costs in the domestic economy, MC_t, finally amount to

$$MC_t=\left[(1-\theta)\left(1+\frac{\theta}{1-\theta}\left[\frac{W_t}{P_{C,t}}\frac{P_{C,t}}{P_{O,t}}\right]^{\eta-1}\right)\right]^{\frac{1}{1-\eta}}\frac{W_t}{P_{C,t}}\frac{P_{C,t}}{P_{H,t}}. \tag{21}$$

Empirical research (*e.g.* Altissimo *et al.* 2006, Bils and Klenow 2004, Taylor 1998) provides ample evidence for price persistence in goods markets. Producers reset prices infrequently. Potential explanations for sluggish adjustment are resetting and information collection costs and contractual obligations.[3] Following Calvo (1983), firms are assumed to set prices in staggered contracts of random duration. In any period, each firm gets to announce a new price with probability 1-ξ, while the previous price remains valid otherwise.

[3] Altissimo *et al*. (2006) and Taylor (1999) also discuss the empirical evidence with regard to various candidate explanations for price persistence.

Given the infrequent adjustment, price setting becomes a problem of dynamic optimization. Firms choose the target price $\widetilde{P}_{h,t}$ such as to maximise the present value of profits over the expected contract duration

$$E_t \sum_{i=0}^{\infty} (\xi\beta)^i \lambda_{t+i} P_{H,t+i} \left(\frac{\widetilde{P}_{h,t}}{P_{H,t+i}} - MC_{h,t+i} \right) Y_{h,t+i} , \tag{22}$$

where λ_{t+1} is the marginal utility of nominal wealth. The firm's first order condition from maximising (22) subject to the demand function (17) equals

$$\widetilde{P}_{h,t} = \frac{\mu}{\mu - 1} \frac{E_t \sum_{i=0}^{\infty} (\xi\beta)^i \lambda_{t+i} MC_{t+i} P_{H,t+i}^{1+\mu} Y_{t+i}}{E_t \sum_{i=0}^{\infty} (\xi\beta)^i \lambda_{t+i} P_{H,t+i}^{\mu} Y_{t+i}} . \tag{23}$$

The first fraction on the left hand side quantifies the price mark-up under monopolistic competition, which implies an inefficiently low level of production. The mark-up size inversely varies with the elasticity of substitution between product varieties and is thus a positive function of the firm's market power.[4]

Given the law of large numbers, the probability of price correction at firm level, 1-ξ, also characterises aggregate price setting. In a given period, the share 1-ξ of domestic producers resets prices, whereas ζ percent of the firms do not adjust. Consequently, the probability ξ is also a measure of aggregate price rigidity.

Domestic GDP prices evolve according to the dynamic equation

[4] Governments could offset the distorting mark-up effect by paying a production or employment subsidy τ and finance the latter by levying a lump-sum tax. In case of $\tau=\mu^{-1}$, the subsidy would exactly offset the mark-up distortion and ensure steady-state production to equal the efficient output under perfect competition. However, practical feasibility of implementing such a subsidy scheme is doubtful (*e.g.* Benigno and Woodford 2005).

$$P_{H,t}^{1-\mu} = (1-\xi)\tilde{P}_{H,t}^{1-\mu} + \xi P_{H,t-1}^{1-\mu}, \tag{24}$$

while the price dispersion term in equation (18) evolves according to

$$\int_0^1 \left(\frac{P_{h,t}}{P_{H,t}}\right)^{-\mu} dh = (1-\xi)\left(\frac{\tilde{P}_{h,t}}{P_{H,t}}\right)^{-\mu} + \xi\left(\frac{P_{H,t}}{P_{H,t-1}}\right)^{\mu} \int_0^1 \left(\frac{P_{h,t-1}}{P_{H,t-1}}\right)^{-\mu} dh. \tag{25}$$

Given that technology and inputs are identical across firms, $P_{h,t}=P_{H,t}$ holds in case of perfectly flexible prices.[5]

2.2 The rest of the world

The rest of the world is unaffected by household and firm behaviour in the small economy, but influences the latter via trade and capital flows. We capture the rest of the world with a simple closed-economy framework. Household utility and welfare are assumed to correspond to equations (1) and (2) respectively. Foreign households face a budget constraint that is equivalent to (3) and where the dividends also include income from oil extraction. This setting gives first order conditions for consumption and labour supply that correspond to (4) and (5). Equating the domestic and world Euler equations yields

$$1 = E_t\left(\frac{P_{C,t+1}}{S_{t+1}P_{C,t+1}^*}\frac{C_{t+1}}{C_{t+1}^*}\right)\frac{S_t P_{C,t}^*}{P_{C,t}}\frac{C_t^*}{C_t},$$

where the asterisks denote variables in the rest of the world, and where S is the nominal exchange rate. If capital markets are perfectly integrated and risk is perfectly diversified, the expectation term on the right hand side reduces to a constant ζ, reflecting the relative wealth of the representative foreign and domestic households. In this case, we obtain the relationship

$$C_t = \zeta \frac{S_t P_{C,t}^*}{P_{C,t}} C_t^* \tag{26}$$

[5] If a subsidy $\tau=\mu^{-1}$ was in place, the flexprice level of production would also equal the level of efficient output.

between foreign and domestic levels of consumption.[6] Assuming equal endowments of domestic and foreign households gives ζ=1.

The representative foreign household consumes a bundle of manufactured goods and oil that both enter a CES consumption utility function

$$C_t^* = \left[(1-\gamma)^{\frac{1}{\varepsilon}} M_t^{*\frac{\varepsilon-1}{\varepsilon}} + \gamma^{\frac{1}{\varepsilon}} O_t^{*\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{27}$$

equivalent to equation (7). Consequently, we also obtain analogous demand functions for non-oil and oil final demand

$$M_t^* = (1-\gamma)\left(\frac{P_{M,t}^*}{P_{C,t}^*}\right)^{-\varepsilon} C_t^* \tag{28}$$

$$O_t^* = \gamma\left(\frac{P_{O,t}^*}{P_{C,t}^*}\right)^{-\varepsilon} C_t^* \quad . \tag{29}$$

Furthermore the law of one price is assumed to hold across countries, implying $P_{F,t}=S_tP_{M,t}^*$. Exports from the small economy to the rest of the world then equal

$$M_{H,t}^* = \alpha\left(\frac{P_{H,t}}{S_tP_{M,t}^*}\right)^{-1} M_t^* \quad . \tag{30}$$

While it is substantial from the small country perspective, the trade volume is too small to affect real wages and the demand for non-oil production in the rest of the world. Entirely driven by foreign pricing decisions, the CPI of the rest of the world reads

$$P_{C,t}^* = \left[(1-\gamma)P_{M,t}^{*\ 1-\varepsilon} + \gamma P_{O,t}^{*\ 1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} . \tag{31}$$

Aggregate world non-oil output equals world demand for non-oil manufactured goods

[6] See Obstfeld and Rogoff (1996) or Galí and Monacelli (2005) for a detailed derivation of (1.26) under perfect international risk sharing.

$$Y_t^* = M_t^* . \tag{32}$$

For simplification, we consider oil as a commodity that has no extraction costs, but a market price, and thus generates a rent. The production of non-oil consumer goods, on the other hand, uses the same technology as production in the small country. To focus on the impact of nominal and real rigidities in the small economy and on their interaction, we furthermore assume prices and wages to be perfectly flexible in the rest of the world across all simulation scenarios. Price flexibility implies the absence of price dispersion (25), so that overall production equals

$$Y_t^* = A_t \left[(1-\theta)^{\frac{1}{\eta}} N_t^{*\frac{\eta-1}{\eta}} + \theta^{\frac{1}{\eta}} O_t^{*\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} . \tag{33}$$

The optimal combination of inputs depends on relative factor prices. Analogously to (19), optimisation yields

$$\frac{O_t^*}{N_t^*} = \frac{\theta}{1-\theta} \left(\frac{W_t^*}{P_{C,t}^*} \frac{P_{C,t}^*}{P_{O,t}^*} \right)^{\eta} \tag{34}$$

as the cost-minimising factor mix. Real marginal production costs amount to

$$MC_t^* = \left[(1-\theta) \left(1 + \frac{\theta}{1-\theta} \left[\frac{W_t^*}{P_{C,t}^*} \frac{P_{C,t}^*}{P_{O,t}^*} \right]^{\eta-1} \right) \right]^{\frac{1}{1-\eta}} \frac{W_t^*}{P_{C,t}^*} \frac{P_{C,t}^*}{P_{M,t}^*} . \tag{35}$$

Firms sell their products under monopolistic competition and set prices with a mark-up over nominal marginal costs. Given fully flexible prices, price setting reduces to a static optimisation problem. Equation (23) therefore simplifies to

$$1 = \frac{\mu}{\mu-1} MC_t^* \tag{36}$$

for the rest of the world and implies constant real marginal costs in non-oil production.

The relative world-market price for oil is exogenously given. It is modelled as an AR (1) process

$$\ln\left(\frac{P_{O,t}^*}{P_{C,t}^*}\right) = \rho_O \ln\left(\frac{P_{O,t-1}^*}{P_{C,t-1}^*}\right) + \varepsilon_{O,t} \quad , \tag{37}$$

where $0 \le \rho_O \le 1$ measures relative price persistence and ε_O is the stochastic disturbance. Rising relative oil prices increase production costs and lower the real wage, which reduces both aggregate supply and total consumption. The impact on the demand for non-oil goods depends on the elasticity of substitution between oil and non-oil goods in the CES functions (7) and (27). The volume of non-oil consumption increases under a high, but declines under a low price elasticity of the consumer demand for oil. Note that a temporary shock to the relative price of oil implies a return of relative prices to steady state, but does not require a return of absolute prices to their initial levels.

3. Optimal monetary policy

Ramsey monetary policy, *i.e.* optimal monetary policy under commitment, derives from an infinite-horizon Lagrangian problem, in which the central bank maximises conditional expected social welfare (1) subject to the full set of constraints that derive from the private sector's behavioural equations and from the market-clearing conditions of the economy (*e.g*. Khan *et al.* 2003, Levin *et al.* 2005). The first-order conditions follow from differentiating the Lagrangian with respect to each variable that is endogenous to monetary policy and from setting these derivatives to zero. We rely on the Levin *et al.* (2005) procedure to compute the first-order conditions and then analyse the behaviour of the economy under optimal policy by combining the first-order conditions with the behavioural equations of the private sector and the market clearing conditions. In this setup, the central bank's first-order conditions take the place of a single interest rate rule. The Ramsey policy ensures optimal stabilisation under the set of exogenous shocks considered and therefore yields the highest possible level of welfare given structural frictions and inefficiencies in the economy.

Approximating the optimal Ramsey solution with a simple interest rate rule would also be interesting, not least because it would allow investigating which inflation measure central banks should target under relative price disturbances such as oil price shocks (see *e.g.* Bodenstein *et al.* 2007, De Fiore *et al.* 2006, Dhawan and Jeske 2007, Kamps and Pierdzioch 2002). However, the present paper has a narrower focus on the monetary policy and welfare consequences of real rigidities and their interactions with nominal ones under oil price – and, more broadly, cost-push – shocks.

4. Simulation scenarios and calibration

We first study impulse responses and carry out welfare analysis for combinations of two different degrees of nominal and real rigidities. We choose Calvo parameter values of $\xi=0.5$ and $\xi=0.8$ for low and high nominal rigidity respectively, which correspond to average price durations of 2 and 5 quarters, and are in line with the empirical findings in Bils and Klenow (2004) and Altissimo *et al.* (2006) about average price adjustment frequencies in the US and the euro area. Low and high real wage rigidity corresponds in the wage equation (6) to $\rho_w=0.79$ and $\rho_w=0.93$, respectively. The two alternative values imply half-lives of deviations of the real wage from its equilibrium level of about 3 quarters and 3 years, respectively, and match the lower and the higher bounds of estimated real wage rigidity in euro area countries (1980-2005) in Arpaia and Pichelmann (2007).

The simulations account for the inefficiency of the steady state under monopolistic competition. The elasticity of substitution between varieties of goods is set to $\mu=6$ in the baseline scenario, which generates a steady-state price mark-up of 20%, and to $\mu=21$ in an alternative scenario, which is close to the value in Leduc and Sill (2006), decreases the mark-up to only 5% and therefore substantially reduces the inefficiency from monopolistic competition.[7] In addition, an

[7] As mentioned in section 3 introducing a production subsidy that lowers or exactly offsets the inefficiency associated with monopolistic competition would constitute an alternative (see *e.g.* Woodford 2003). In ad-

analysis of the welfare effects of interactions between nominal and real rigidities in Section 5 is carried out within the parameter space of ξ=0.5-0.8 for nominal and ρ_w=0.75-0.93 for real rigidity and grid intervals of 0.05. All calculations of first and second moments and the welfare comparison rely on a second-order approximation of the model in Dynare 4.[8]

The calibration of the remaining parameters adopts standard choices from the literature and is summarised in Table 1. It assumes logarithmic consumption utility, *i.e.* unit intertemporal elasticity of substitution, and unit elasticity of substitution between imports and exports of manufactured goods. The elasticity of labour supply of 0.4 equals the value in De Fiore *et al.* (2006). The share of oil in the consumption basket is set equal to 7% and lies in between the euro area (4.5%) and US (8.5%) calibration of the consumption share of fuel and gas in De Fiore *et al.* (2006), with a low elasticity of substitution of 0.09 between oil and manufactured goods. The input share of oil in the production function is 2.5% (see Backus and Crucini 2000, De Fiore *et al.* 2006), which is slightly higher than the 2% in Carlstrom and Fuerst (2006). As in the latter, the elasticity of substitution between oil and labour in production is set to 0.59.

Table 1 about here

Oil prices are modelled as a temporary but highly persistent shock to the relative price of oil in the world market (37), with a persistence parameter ρ_O=0.95. Impulse responses are based on an initial doubling of the relative price of oil, which for the log-linear formulation (37) implies

dition to the questionable realism of a lump-sum financed production subsidy, comparison between two distinct values for the elasticity of substitution also allows interpreting the results as comparing different degrees of product market competition.

[8] Kim and Kim (2003, 2007) show that welfare evaluation combining a second-order approximation of utility with first-order approximations of the model equations is inaccurate around a distorted steady state.

ε_t=0.69. As we treat oil as the only commodity and calibrate it to the share of fuel and gas in the CPI and in production, the oil shock may also be seen as a shortcut for a global commodity price shock.

5. Results

We now analyse the effects of real wage rigidity and its interaction with price stickiness within the calibrated model in the presence of global oil price shocks and under optimal monetary commitment. Table 2 reports the first and second moments for output, the output gap[9], inflation and the nominal interest rate for the two alternative degrees of steady-state distortion – *i.e.* the 20% (μ=6) and 5% (μ=21) price mark-ups, respectively – and six possible combinations of nominal and real rigidities.

Table 2 about here

Regardless of the degree of nominal inertia, the volatility of log output, the output gap, GDP price inflation and the nominal interest rate are found to rise with the degree of real wage rigidity. However, for a given degree of non-zero real wage rigidity, higher nominal inertia reduces fluctuations in these variables. These findings hold for both values of the steady state distortion. Whatever the combination of nominal and real rigidities, a larger steady-state distortion always coincides with higher inflation volatility. Table 2 also gives the mean values for log output, the output gap, inflation and the nominal interest rate under the different combinations of the rigidity

[9] Blanchard and Galí (2007a) refer to this variable as the *welfare-relevant* output gap. It measures the log difference between actual output and production under fully flexible prices and wages. Thus, the latter measure of potential production displays the optimal unconstrained behaviour of household and firms in reaction to the exogenous shock.

parameters.[10] While mean output decreases in the degree of both nominal and real inertia, mean inflation increases with real wage rigidity but decrease with nominal stickiness. The fall of average GDP price inflation under lower frequencies of price adjustment reduces the distortionary impact of the shock on consumer choices.

Figure 1 about here

The impulse responses in Figure 1 further illustrate the findings on macroeconomic volatility under different degrees of nominal and real rigidities derived from Table 2. This chart plots nominal interest rates, *int*, real interest rates, *rint*, CPI and GDP price inflation, *pi_cpi* and *pi_gdp*, the output gap, *y_gap*, log output, *y*, log consumption, *c*, log employment, *n*, and the log relative oil price on world markets, *poc_row*, in deviations from steady-state levels. Real rigidities essentially lengthen the time needed for the economy to return to its steady-state, while the degree of price rigidity primarily affects the initial amplitude of impulse responses. For a given degree of real wage rigidity, more flexible prices amplify initial peaks, although such peaks quickly decay in case of low real persistence.

Figure 1 suggests an important role for the nominal-real rigidity interaction in shaping interest rate, output and inflation responses to oil-price shocks and cost-push shocks more broadly. Instead of reinforcing the effect of real wage persistence, sticky prices dampen the infla-

[10] Unlike under first-order approximation, the mean values from second-order approximation differ from the deterministic steady state in a stochastic environment. The deterministic steady state characterises the equilibrium in the absence of shocks and ignoring future shocks. The stochastic steady state, on the other hand, denotes the equilibrium in the absence of shocks, but taking into account the likelihood of future shocks. Given their impact on shock propagation and welfare, the degrees of both nominal and real rigidities affect the stochastic means.

tion and output response to shocks, for a given level of real rigidity. Prices flexibility reduces the sacrifice ratio, *i.e.* the output loss required to bring down inflation, but it also increases the sensitivity of inflation to production costs. Consequently, flexible prices amplify the initial inflation response to oil price shocks. In a context where real wages respond little to the decline in output and labour demand, higher initial inflation pushes up the nominal wage, thereby reinforcing inflationary pressures. In this context, the monetary authority concerned about inflation and the associated inefficiency reacts more strongly and engineers a larger output contraction. By contrast, higher nominal price rigidity dampens initial inflationary pressures and improves both inflation and output stabilisation, for a given degree of real rigidity. In other words, when real rigidities are present in the economy, price stickiness dampens the initial goods price response to cost-push shocks and mitigates the second-round effect from nominal wages on production costs.

The implications for household welfare, studied in Table 3, are unambiguous. First, regardless of the steady-state inefficiency and the degree of price stickiness, the loss strongly *increases* in the degree of real rigidity. For example, under a 20% steady-state mark-up (μ=6) and a low degree of price stickiness (ξ = 0.5), the loss compared with the fully flexible economy is about 1.7% of steady-state consumption if real wage rigidity is high (ρ_w = 0.93) versus only 0.3% if it is moderate (ρ_w = 0.79). Second, and most interestingly, higher nominal rigidity *reduces* the welfare loss for a *given* degree of real rigidity. For example, under a 20% steady-state mark-up (μ=6) and a high degree of real wage rigidity (ρ_w = 0.93), the loss compared with the fully flexible economy is about 1.7% of steady-state consumption if price stickiness is low (ξ = 0.5) versus only 0.9% if it is high (ξ = 0.8). It is also worth noting that losses vary inversely with the price mark-up. The closer the distorted equilibrium is to the efficient steady state, the stronger the amplitude of output and inflation responses (see also Figure 1).

Table 3 about here

It should be stressed that this pattern of welfare effects is a general finding that does not hinge on the particular choice of nominal and real rigidity parameters featured in Table 3. As an illustration, Figure 2 plots the welfare loss relative to the fully flexible economy (expressed as a percentage of steady-state consumption) across the parameter space ξ=0.50-0.80 and ρ_w=0.75-0.95, with grid intervals of 0.05, for a 20% steady-state mark-up distortion (μ=6). The surface shows the loss to increase monotonically in the degree of real rigidity, but to decrease in the degree of price stickiness for a given degree of real rigidity. While losses are generally more sensitive to real than to nominal inertia, the importance of price stickiness increases with the degree real wage rigidity.

Figure 2 about here

6. Conclusion

This paper explores the welfare effects of real wage rigidities and their interaction with price stickiness, two issues which somewhat surprisingly have surfaced only recently in the New-Keynesian literature. To this end, we focus on a major cost-push shock, namely an oil shock, and build up a new small open economy DSGE model where oil is used both as a production input and as a final consumption good. Impulse responses to a persistent oil price shock are then presented, and welfare analysis undertaken, for a plausible set of nominal and real rigidity parameters based on values found in recent empirical analyses for European countries and the US. We find that under oil – and, more broadly, cost-push – shocks, the welfare cost of real rigidities can be very large, up to 2.5% of steady state consumption under high but yet plausible parameter values. Most interestingly, in a typical "tale of the second best", higher nominal inertia is found to be welfare-enhancing in the presence of real wage rigidities, as it dampens the initial consumer goods price response and mitigates the second-round effects from nominal wages on production costs.

From a theoretical perspective, these findings confirm Blanchard and Galí (2007a) and suggest that monetary economists should pay greater attention to real rigidities than they have done in the recent past. From a policy perspective, it appears that in the presence of cost-push shocks and real wage rigidities, reducing price stickiness is *not* welfare-enhancing. In particular, in most of Continental Europe, greater product market competition advocated by central bankers would not actually help the conduct of monetary policy under cost-push shocks, unless real wage rigidities are addressed *first* through labour market reforms.

References

Altissimo, Filippo, Michael Ehrmann, and Frank Smets. (2006). "Inflation Persistence and Price-Setting Behaviour in the Euro Area: A Summary of the IPN Evidence." ECB Occasional Paper 46, European Central Bank, June 2006.

Arpaia, Alfonso, and Karl Pichelmann. (2007). "Nominal and Real Wage Flexibility in EMU." International Economics and Economic Policy 4, 299-328.

Atkeson, Andrew, and Patrick Kehoe. (1999). "Models of Energy Use: Putty-Putty versus Putty-Clay." American Economic Review 89, 1028-1043.

Backus, David, and Mario Crucini. (2000). "Oil Prices and the Terms of Trade." Journal of International Economics 50, 185-213.

Benigno, Pierpaolo, and Michael Woodford. (2005). "Inflation Stabilization and Welfare: The Case of a Distorted Steady State." Journal of the European Economic Association 3, 1185-1236.

Bils, Mark, and Peter Klenow. (2004). "Some Evidence on the Importance of Sticky Prices." Journal of Political Economy 112, 947-984.

Blanchard, Olivier, and Jordi Galí. (2007a). "Real Wage Rigidities and the New Keynesian Model." Journal of Money, Credit and Banking 39, 35-65.

Blanchard, Olivier, and Jordi Galí. (2007b). "The Macroeconomic Effects of Oil Shocks: Why Are the 2000s So Different from the 1970s?" NBER Working Paper 13368, National Bureau of Economic Research, September 2007.

Bodard, Vincent, Olivier Pierrard, and Henri Sneessens. (2006). "Calvo Wages in a Search Unemployment Model." IZA Discussion Paper 2521, Institute for the Study of Labor, December 2006.

Bodenstein, Martin, Christopher Erceg, and Luca Guerrieri. (2007). "Optimal Monetary Policy in a Model with Distinct Core and Headline Inflation." Mimeo, September 2007.

Calvo, Guillermo. (1983). "Staggered Prices in a Utility-Maximizing Framework." Journal of Monetary Economics 12, 383-398.

Campolmi, Alessia. (2006). "Which Inflation to Target? A Small Open Economy with Sticky Wages Indexed to Past Inflation." Department of Economics and Business Working Paper 961, Universitat Pompeu Fabra, March 2006.

Carlstrom, Charles, and Timothy Fuerst. (2006). "Oil Prices, Monetary Policy, and Counterfactual Experiments." Journal of Money, Credit and Banking 38, 1945-1958.

Christoffel, Kai, and Tobias Linzert. (2005). "The Role of Real Wage Rigidity and Labor Market Frictions for Unemployment and Inflation Dynamics." ECB Working Paper 556, European Central Bank, November 2005.

De Fiore, Fiorella, Giovanni Lombardo, and Victor Stebunovs. (2006). “Oil Price Shocks, Monetary Policy Rules and Welfare.” Mimeo, February 2006.

Dhawan, Rajeev, and Karsten Jeske. (2007). “Taylor Rules with Headline Inflation: A Bad Idea.” Federal Reserve Bank of Atlanta Working Paper 2007-14, Federal Reserve Bank of Atlanta, July 2007.

Faia, Ester. (2007). “Ramsey Monetary Policy with Labour Market Frictions”, ECB Working Paper 707, European Central Bank, January 2007.

Galí, Jordi, and Tommaso Monacelli. (2005). “Monetary Policy and Exchange Rate Volatility in a Small Open Economy.” Review of Economic Studies 72, 707-734.

Kamps, Christophe, and Christian Pierdzioch. (2002). “Monetary Policy Rules and Oil Price Shocks.” Kiel Institute of World Economics Working Paper 1090, Kiel Institute of World Economics, January 2002.

Khan, Aubhik, Robert King, and Alexander Wolman. (2003). “Optimal Monetary Policy.” Review of Economic Studies 70, 825-860.

Kim, Jinill, and Sunghyun Kim. (2003). “Spurious Welfare Reversals in International Business Cycle Models.” Journal of International Economics 60, 471-500.

Kim, Jinill, and Sunghyun Kim. (2007). “Two Pitfalls of Linearization Methods.” Journal of Money, Credit and Banking 39, 995-1001.

Leduc, Sylvain, and Keith Sill. (2006). “Monetary Policy, Oil Shocks, and TFP: Accounting for the Decline in U.S. Volatility.” Board of Governors of the Federal Reserve System International Finance Discussion Paper 873, Board of Governors of the Federal Reserve System, August 2006.

Levin, Andrew, Alexei Onatski, John Williams, and Noah Williams. (2005). “Monetary Policy under Uncertainty in Micro-Founded Macroeconometric Models.” NBER Working Paper 11523, National Bureau of Economic Research, August 2005.

Obstfeld, Maurice, and Kenneth Rogoff. (1996). Foundations of International Macroeconomics. Cambridge, MA.: MIT Press.

Rabanal, Pau. (2001). “Real Wage Rigidities, Endogenous Persistence and Optimal Monetary Policy.” Mimeo, 2001.

Roeger, Werner. (2005). “International Oil Price Changes: Impact of Oil Prices on Growth and Inflation in the EU/ OECD.” International Economics and Economic Policy 2, 15-32.

Taylor, John. (1998). “Staggered Price and Wage Setting in Macroeconomics.” NBER Working Paper 6754, National Bureau of Economic Research, October 1998.

Woodford, Michael. (2003). Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton: Princeton University Press.

Parameter	Symbol	Value
Discount rate	β	0.99
Elasticity of labour supply	φ^{-1}	0.40
Steady-state trade openness in manufactured goods	α	0.30
Steady-state consumption share of oil	γ	0.07
Substitution elasticity between oil and non-oil goods	ε	0.09
Steady-state input share of oil	θ	0.02
Substitution elasticity between oil and labour	η	0.59
Substitution elasticity between non-oil types of goods	μ	6; 21
Nominal price inertia	ξ	0.50-0.80
Real wage inertia	ρ_w	0.75-0.95
Persistence of oil shock	ρ_O	0.95
Standard deviation of oil shock	σ_ε	0.69

Table 1: The model calibration

	Rigidities		Mean					Standard deviation				
μ	ρ_w	ξ	y	y_gap	π_{CPI}	π_{GDP}	i	y	y_gap	π_{CPI}	π_{GDP}	i
6	0.00	0.50	-0.1324	-0.0000	0.0001	0.0001	0.0099	0.0898	0.0012	0.0554	0.0021	0.0039
6	0.00	0.80	-0.1326	-0.0002	0.0001	0.0001	0.0098	0.0878	0.0058	0.0562	0.0015	0.0056
6	0.79	0.50	-0.1337	-0.0014	0.0021	0.0021	0.0121	0.1052	0.0363	0.0567	0.0148	0.0088
6	0.79	0.80	-0.1341	-0.0017	0.0007	0.0007	0.0106	0.0952	0.0178	0.0543	0.0047	0.0032
6	0.93	0.50	-0.1390	-0.0066	0.0087	0.0087	0.0187	0.1489	0.0907	0.0637	0.0314	0.0124
6	0.93	0.80	-0.1393	-0.0069	0.0029	0.0029	0.0129	0.1211	0.0539	0.0536	0.0098	0.0044
21	0.00	0.50	-0.0902	-0.0000	0.0000	0.0000	0.0099	0.0875	0.0005	0.0538	0.0008	0.0035
21	0.00	0.80	-0.0903	-0.0001	0.0001	0.0001	0.0098	0.0865	0.0033	0.0547	0.0007	0.0050
21	0.79	0.50	-0.0914	-0.0012	0.0018	0.0018	0.0118	0.1065	0.0433	0.0466	0.0077	0.0185
21	0.79	0.80	-0.0921	-0.0019	0.0008	0.0008	0.0108	0.0972	0.0259	0.0500	0.0028	0.0063
21	0.93	0.50	-0.0964	-0.0062	0.0077	0.0077	0.0173	0.1570	0.1040	0.0448	0.0168	0.0231
21	0.93	0.80	-0.0986	-0.0084	0.0033	0.0033	0.0134	0.1312	0.0702	0.0468	0.0060	0.0102

Table 2: Means and standard deviations for different combinations of nominal and real rigidities

	Rigidities		Welfare loss relative to the economy with flexible prices and wages	
μ	ρ_w	ξ	Value	% of steady-state consumption
6	0.00	0.50	0.0	0.0
6	0.00	0.80	0.0	0.0
6	0.79	0.50	-0.3	0.3
6	0.79	0.80	-0.1	0.1
6	0.93	0.50	-1.7	1.7
6	0.93	0.80	-0.9	0.9
21	0.00	0.50	0.0	0.0
21	0.00	0.80	0.0	0.0
21	0.79	0.50	-0.5	0.5
21	0.79	0.80	-0.3	0.3
21	0.93	0.50	-2.4	2.4
21	0.93	0.80	-1.5	1.5

Table 3: Means and standard deviations for different combinations of nominal and real rigidities

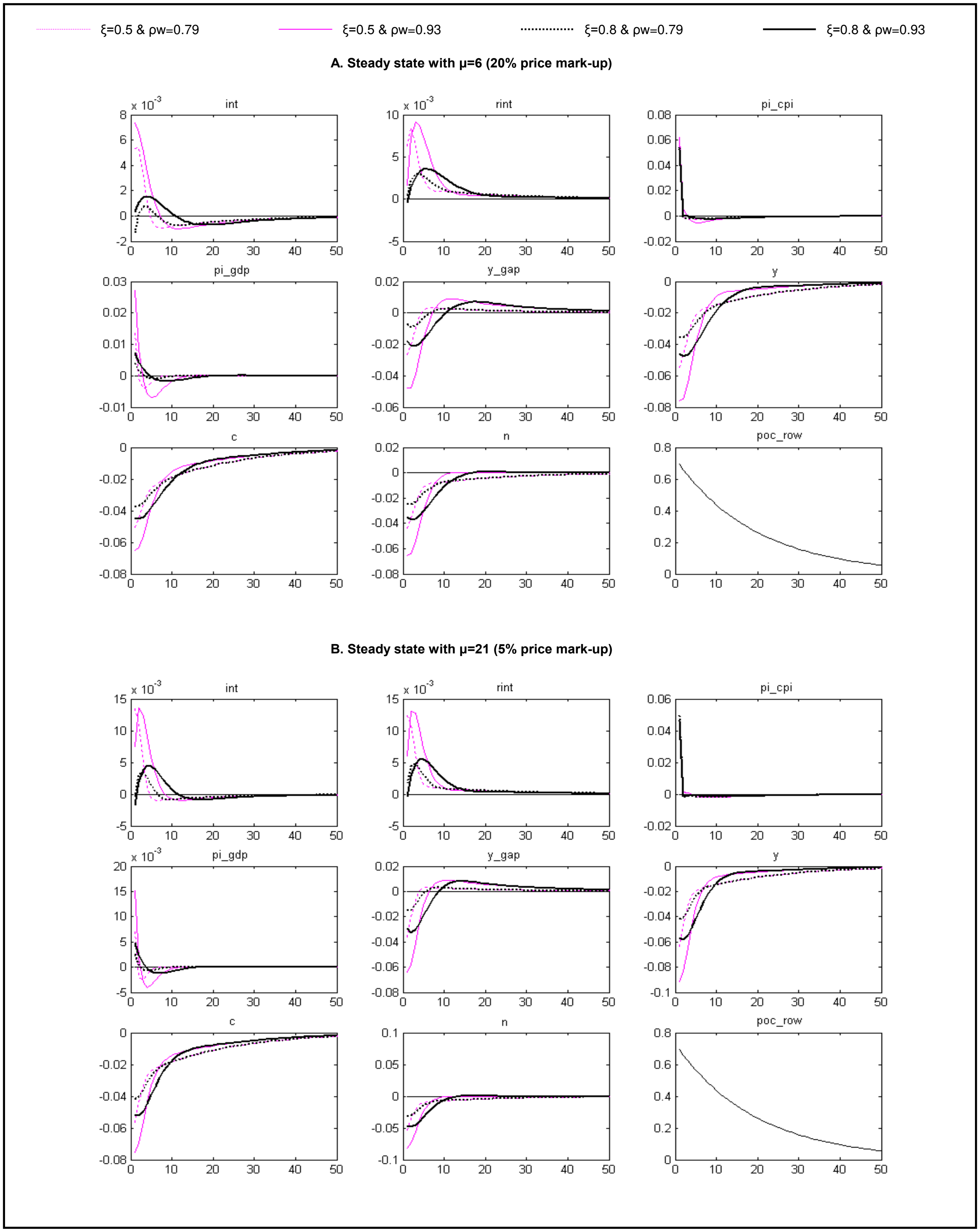

Figure 1: Impulse responses to the oil price shock under different degrees of nominal and real rigidities

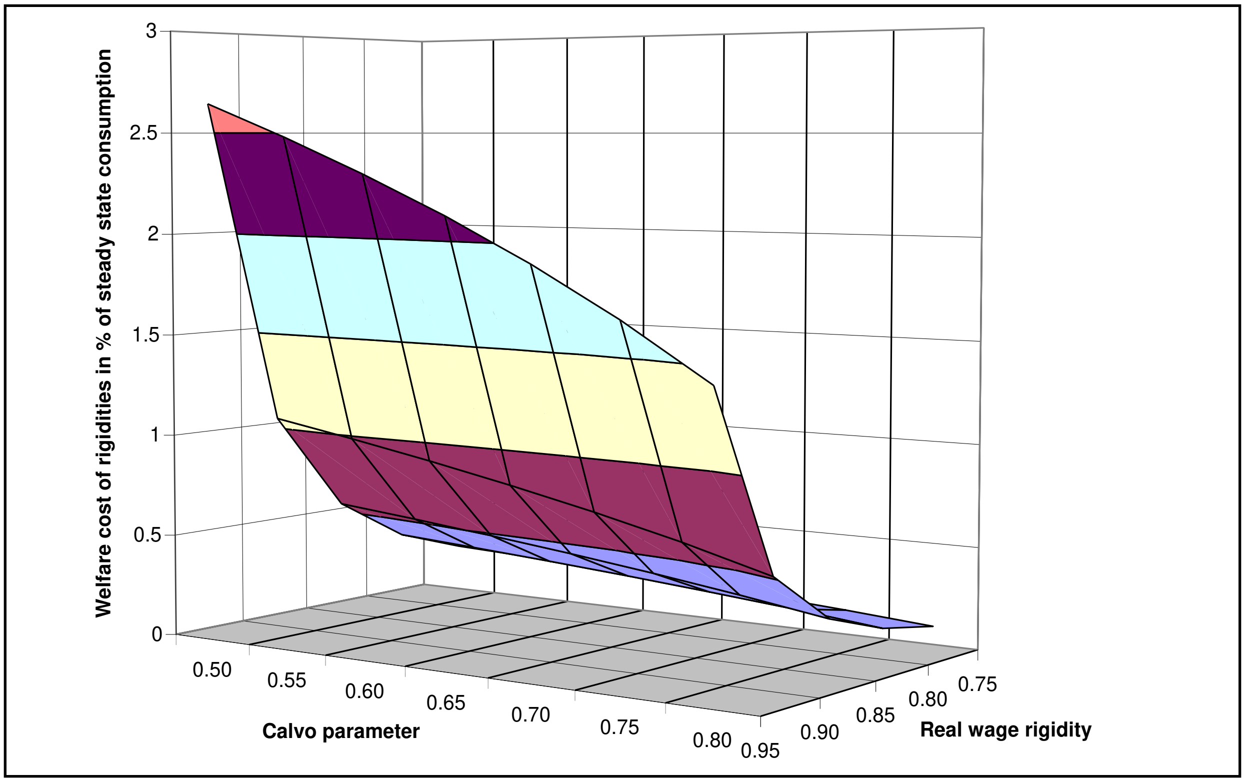

Figure 2: Welfare losses across a grid of nominal and real rigidity values