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Magnus Jonsson and Stefan Palmqvist

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Inflation, Markups and Monetary Policy*

Magnus Jonsson†and Stefan Palmqvist‡

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Abstract

The correlation between persistent changes in the markup in one sector of an economy and the inflation rate is quantified in a 2-sector dynamic general equilibrium model. How this relationship is affected by monetary policy is also studied. We find that the correlation is in general positive under an exogenous money growth rule as well as under an inflation targeting rule. That is, a decrease of the markup leads to a decrease in the CPI-inflation rate. However, if inflation is measured by an optimal price index that also includes the wage rate the correlation is slightly negative. That is, a decrease in the markup leads to higher inflation rates. This is due to higher wage rates.

The correlation is sensitive to whether the policy rule includes an output term. If monetary policy accommodates output strongly the correlation is negative. A decrease in the markup leads to higher inflation rates, as measured by both the CPI and the optimal price index.

JEL classification: D43, E31, E52

Keywords: Price indices, monopolistic competition, monetary policy rules.

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†Research Department, Sveriges Riksbank, SE-103 37 Stockholm, Sweden, e-mail: magnus.jonsson@riksbank.se.

‡Monetary Policy Department, Sveriges Riksbank, SE-103 37 Stockholm, Sweden, e-mail: stefan.palmqvist@riksbank.se.

1 Introduction

Economies in Europe and the U.S. are characterized by a large number of industries or sectors with various degrees of competition. The degree of competition in a specific sector may change over time due to political decisions or other reasons. For example, there has been a recent deregulation of network industries like telecom, energy and water that may lead to higher competition in these sectors.

In general there are, of course, several reasons why competition may be imperfect and vary between sectors; few buyers and sellers, entry barriers or differentiated goods. We will focus the analysis on a market structure where there is a large number of firms that sell closely related but not homogenous goods. This market structure is named monopolistic competition and was introduced into macroeconomics by Blanchard and Kiyotaki (1987) and later into an RBC-framework by Hornstein (1993). It has been a popular modelling device in monetary economics since it is possible to model the price setting by firms and to explain why a firm may accommodate small increases in demand at unchanged prices. However, monopolistic competition in itself does not rationalize nominal price stickiness.

This paper analyzes how increased competition in one sector of the economy affects the inflation rate. More specifically, the correlation between persistent changes in the markup and inflation is quantified. We also show how this relationship is affected by monetary policy.

The framework is the simplest possible. Since a change in the markup may take place in one sector of the economy we need a model with at least two sectors in order to study relative price effects. For simplicity, we assume two sectors. Each sector produces one good that can be used for consumption and investment. The first sector is characterized by monopolistic competition where firms set their price as a markup over marginal cost. In the second sector we assume perfect competition; that is, price equals marginal cost. Labor is homogenous and freely mobile between the two sectors. Capital on the other hand is sector specific and cannot be freely moved between the sectors.

Money is introduced through a cash-in-advance constraint, which is a simple way to model the fact that money facilitates transactions. There are no nominal rigidities or liquidity effects in the model. Hence, monetary policy affects the inflation rate through its effect on inflation expectations. In accordance with empirical evidence, Sims (1992) and Leeper et al. (1996), monetary policy has only small effects on the real economy.

The monetary authority is assumed to follow a money growth rule. In practice, basically all central banks have a target for a short term nominal interest rate (the Fed funds rate in the case of the U.S.). The Fed may still be viewed as following a money rule though. It injects funds (money) each day, then allows the market to work out the market-clearing Fed funds rate. The Fed does not stand ready to lend funds at the Fed funds rate. There is a sense in which any money rule can be achieved using an interest rate, and vice versa.

A more fundamental reason for using a money rule in our model is to avoid indeterminacy problems. It is well known in the literature that indeterminacy and sunspot equilibria may arise when a monetary authority follows an interest rate rule. These equilibria may lead to very bad outcomes. In theory, a money rule or target may avoid those outcomes since it helps stabilizing inflation expectations and therefore inflation. This is discussed in, for example, Carlstrom and Fuerst (2001). The ECB is an example of a central bank that in addition to an inflation target also has a target for the money growth rate.[1]

There is no consensus in the empirical literature regarding the correlation between markups and inflation. Bénabou (1992) examines how retail markups are affected by inflation and finds a negative correlation. The theoretical idea behind his results is that higher trend inflation leads to more price dispersion which in turn promotes search and increases competition. Neiss (2001) investigates the relationship between average inflation and the markup for the OECD countries. She finds, in contrast to Bénabou, a positive correlation. Her hypothesis is that reduced competition among firms increases the incentives for the monetary authority to use inflation to raise output. Chirinko and Fazzari (1999) examine the relationship between market power and inflation in eleven U.S.-industries and find a positive correlation. Finally, Banerjee and Russell (2000) find a long-run negative correlation between inflation and the markup for the aggregate U.S. economy and for twelve of the fifteen sectors.

We illustrate and discuss the central mechanisms in the model by conducting impulse-response analyses. The correlation between markups and inflation is then quantified by doing stochastic simulations under different monetary policy regimes. We also quantify the difference between the CPI and an optimal nominal price index, where the latter also includes the nominal wage rate

We find that the correlation between persistent changes in the markup in one sector of the economy and CPI-inflation is in general positive under an exogenous

[1] The operating target of the ECB is a short term nominal interest rate. However, in addition to a target for the inflation rate the ECB also has a reference value for the money growth rate.

money growth rule as well as under an inflation targeting rule. That is, a decrease of the markup leads to a decrease in the CPI-inflation rate. However, if inflation is measured by an optimal nominal price index that also includes the wage rate the correlation is slightly negative. That is, a decrease in the markup leads to higher inflation rates. This is due to higher wage rates.

The correlation is sensitive to whether the policy rule includes an output term. If monetary policy accommodates output strongly the correlation is negative. A decrease in the markup leads to higher inflation rates, as measured by both the CPI and the optimal nominal price index. This is because lower markups increases output which in turn leads to higher inflation if the central bank accommodates output strongly. We also perform sensitivity analysis with respect to the parameter values. This analysis shows that the results are robust to reasonable changes in the parameter values.

The paper is organized as follows. In section 2 we present the two-sector dynamic general equilibrium model with money, define the equilibrium, and calibrate the model to broadly fit stylized facts of the Euro area. In section 3 we derive an optimal nominal price index as well as define the CPI in terms of our model. Section 4 reports our quantitative results from the impulse-response analysis and the stochastic simulations. Finally, section 5 concludes.

2 Theoretical framework

This section presents the two-sector dynamic general equilibrium model with money. The first sector is characterized by imperfect (monopolistic) competition and the second by perfect competition. The economy consists of infinitively-lived households, firms, and a monetary authority (i.e. a central bank). Households maximize utility, firms maximize profits, and the central bank follows a simple money growth rule.

2.1 Households

The economy is inhabited by a large number of households. Each household has preferences, $\mathcal{U}$, over two consumption goods, c_1 and c_2, and leisure, ℓ, according to

$$\mathcal{U} = \mathrm{E}\left[\sum_{t=0}^{\infty} \beta^t U\left(c_{1,t}, c_{2,t}, \ell_t\right)\right], \tag{1}$$

where t denotes time, E the unconditional expectation operator, $U(\cdot)$ the utility function, and β the subjective discount factor. We parameterize the utility-function as log-utility

$$U(c_{1,t}, c_{2,t}, \ell_t) = \alpha \ln(c_t) + (1-\alpha) \ln \ell_t, \tag{2}$$

where c is an aggregate of c_1, c_2 and α denotes the weight on consumption relative to leisure. The consumption aggregator is of the following form

$$c_t = (c_{1,t})^{\alpha_1} (c_{2,t})^{(1-\alpha_1)}, \tag{3}$$

where α_1 measures the weight on c_1 relative to c_2.

If we let good 1 be the numeraire, the household's intertemporal budget constraint, in terms of good 1, is given by

$$c_{1,t}+p_{2,t}c_{2,t}+i_{1,t}+p_{2,t}i_{2,t}+\frac{m_{t+1}}{p_t^m} = r_{1,t}k_{1,t}+r_{2,t}k_{2,t}+w_t h_t+\frac{m_t}{p_t^m}+T_t+\Pi_t, \tag{4}$$

where p_2 denotes the price of good 2 in terms of good 1, k the stock of capital, i investments in the capital stock, r the rental rate of capital, w the wage rate, h total hours worked, p^m the monetary price of good 1, m the money stock, Π real profits from the intermediary producing firms, and, finally, T denotes real transfers from the central bank; that is, the seigniorage. In general, capital letters denote aggregates.[2]

The households have a time constraint

$$\ell_t + h_t = 1; \tag{5}$$

that is, the time endowment is normalized to 1.

Money is introduced through a cash-in advance constraint given by[3]

$$c_{1,t} + p_{2,t}c_{2,t} = \frac{m_t}{p_t^m} + T_t. \tag{6}$$

Finally, the laws of motion for capital in sector 1 and 2 are given by

$$k_{1,t+1} = i_{1,t} + (1-\delta)k_{1,t}, \text{ and} \tag{7}$$

$$k_{2,t+1} = i_{2,t} + (1-\delta)k_{2,t}, \tag{8}$$

[2] With a slight abuse of notation, we let Π denote profits and π denote the inflation rate later in the paper.

[3] We could also have introduced money by including real money balances in the utility-function. However, as will become more clear later, the optimal nominal price index would then include nominal money holdings. As this makes the comparison with the CPI less clear-cut, we choose to introduce money through a cash-in-advance constraint.

where δ denotes the rate of depreciation.

The first order conditions for the households' maximization problem can be summarized by the following four conditions

$$p_{2,t} = \frac{U'_{c_{2,t}}}{U'_{c1,t}}, \tag{9}$$

$$w_t = \frac{U'_{\ell_t}}{\beta \mathrm{E_t}\left(\frac{U'_{c_{1,t+1}}}{\pi^m_{t+1}}\right)}, \tag{10}$$

$$\mathrm{E_t}\left(\frac{U'_{c_{1,t+1}}}{\pi^m_{t+1}}\right) = \beta \mathrm{E_t}\left(\frac{U'_{c_{1,t+2}}}{\pi^m_{t+2}}(1 + r_{1,t+1} - \delta)\right), \text{ and} \tag{11}$$

$$\mathrm{E_t}\left(p_{2,t}\frac{U'_{c_{2,t+1}}}{p_{2,t+1}\pi^m_{t+1}}\right) = \beta \mathrm{E_t}\left(\frac{U'_{c_{2,t+2}}}{p_{2,t+2}\pi^m_{t+2}}\left(p_{2,t+1}\left(1-\delta\right) + r_{2,t+1}\right)\right), \tag{12}$$

where $\mathrm{E_t}$ is the expectation operator conditional on information in period t and

$$\pi^m_{t+1} = \frac{p^m_{t+1}}{p^m_t}. \tag{13}$$

The first condition, (9), gives the familiar result that the marginal rate of substitution between good 1 and good 2 equals the relative price. The next condition, (10), says that the marginal rate of substitution between leisure and consumption equals the real wage. The expectation operator is due to the cash-in-advance constraint. The last two conditions, (11) and (12), are the standard Euler equations relating consumption growth to the net return on capital.

2.2 Firms

There are two sectors of production in this economy: sector 1 is characterized by imperfect (monopolistic) competition and sector 2 by perfect competition. We start by describing the sector with monopolistic competition; that is, sector 1. There are two types of firms; firms producing final goods and firms producing intermediate goods. The final good firms behave competitively and use intermediate goods as inputs. There is free entry into this market, consequently profits will be zero. Formally, the maximization problem for firms producing final goods is

$$\max_{x^i}\left[y_{1,t} - \int_0^1 p^i_t x^i_t di\right], \tag{14}$$

where y_1 denotes output of the final good, x^i the input of intermediate good i and p^i the price of input i. The technology for producing final goods from intermediate goods is given by

$$y_{1,t} = \left(\int_0^1 (x_t^i)^{1/\nu} di \right)^{\nu}, \tag{15}$$

where the elasticity of substitution between goods is given by $\nu/(1-\nu)$.[4] The first order condition for profit maximization yields the following demand function for input i,

$$y_{1,t}^i = \left(\frac{1}{p_t^i} \right)^{\frac{\nu}{\nu-1}} y_{1,t}, \tag{16}$$

that is, the price elasticity of the demand functions are constant and given by $\nu/(1-\nu)$.

Intermediate goods firms act as monopolists and face the demand function y_1^i for good i. Each good is produced by a single firm. The firms take the wage rate, the rental rate of capital and the prices of the other intermediate firms as given when choosing prices, labor and capital to maximize profits. There is no entry or exit of intermediate firms. The potential profits are allocated to the households. It is convenient to solve their maximization problem by first defining the cost function. Firm i has a cost function for a given level of output defined by

$$C^i(r_{1,t}, w_t, x_t^i) = \min_{h_1^i, k_1^i} \left[w_t h_{1,t}^i + r_{1,t} k_{1,t}^i \right], \tag{17}$$

subject to the increasing returns to scale production function

$$x_t^i = (k_{1,t}^i)^{\theta_1} (h_{1,t}^i)^{1-\theta_1} - \chi, \tag{18}$$

where χ denotes a fixed cost independent of the scale of production and θ_1 denotes capital's share of output. The profit maximization problem can then be formulated in the following way

$$\max_{p^i} \left[p_t^i y_{1,t}^i - C^i(r_{1,t}, w_t, y_{1,t}^i) \right]. \tag{19}$$

The first order conditions and profits for the intermediate firms are given by

$$p_t^i = \nu MC_t^i, \tag{20}$$

[4]Note that in the simulations we assume that ν is time-varying and follows an (exogenous) AR(1)-process.

$$w_t = (1-\theta_1)\frac{1}{\nu}\left(\frac{k^i_{1,t}}{h^i_{1,t}}\right)^{\theta_1}, \tag{21}$$

$$r_{1,t} = \theta_1\frac{1}{\nu}\left(\frac{h^i_{1,t}}{k^i_{1,t}}\right)^{1-\theta_1}, \tag{22}$$

$$\Pi^i_t = \left(1-\frac{1}{\nu}\right)(k^i_{1,t})^{\theta_1}(h^i_{1,t})^{1-\theta_1} - \chi, \tag{23}$$

where MC^i denotes the marginal cost to firm i of producing an additional unit of output. These first order conditions say, among other things, that intermediate firms set their price as a markup over marginal cost, where the markup equals ν. Note that the markups give rise to similar distortions as an income tax. When solving for the equilibrium we will assume a symmetric equilibrium where all intermediate firms produce at the same level, employ the same labor and capital, and charge the same relative price.

In sector 2 there is a large number of perfectly competitive firms. Each firm rents capital and employs labor in order to maximize profits, taking factor prices as given. The maximization problem is formally given by

$$\max_{k_2,h_2}\left[p_{2,t}F(k_{2,t},h_{2,t}) - r_{2,t}k_{2,t} - w_t h_{2,t}\right], \tag{24}$$

where $F(\cdot)$ denotes the production function. The production function is assumed to be a constant-returns-to-scale function; that is,

$$F(k_{2,t},h_{2,t}) = k^{\theta_2}_{2,t}h^{1-\theta_2}_{2,t}, \tag{25}$$

where θ_2 denotes capital's share of income. Maximization yields the following first order conditions

$$w_t = p_{2,t}(1-\theta_2)\left(\frac{k_{2,t}}{h_{2,t}}\right)^{\theta_2}, \tag{26}$$

$$r_{2,t} = p_{2,t}\theta_2\left(\frac{h_{2,t}}{k_{2,t}}\right)^{1-\theta_2}, \tag{27}$$

that is, the wage rate equals the marginal product of labor while the rental rate of capital equals the marginal product of capital.

2.3 The monetary authority

The monetary authority prints money according to a money growth rule given by

$$M_t^s = g_t M_{t-1}^s \tag{28}$$

where M^s denotes aggregate money supply and g the growth rate of the money supply. We will study the effects of different policy rules. The different rules are special cases of the following general case

$$g_t = \bar{g} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\varpi_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\varpi_Y}, \tag{29}$$

where $\bar{g}$ denotes the steady state money growth rate, which is exogenously given, π denotes a measure of the inflation rate to be defined later, and Y denotes aggregate GDP.[5] The endogenous part of monetary policy consists of reactions to deviations of inflation from steady state and the growth rate of GDP. The degree of responsiveness is determined by the parameters $\varpi_\pi < 0$ and $\varpi_Y > 0$. An interpretation of this policy rule is that the monetary authority has an inflation target given by $\bar{\pi}$ and accommodates output fluctuations.

We abstract from fiscal policy; the monetary authority therefore simply fulfills the budget constraint

$$T_t = \frac{M_t^s - M_t}{p_t^m}. \tag{30}$$

2.4 Equilibrium

We assume a symmetric and competitive equilibrium in which behavior is identical across households and across firms. This allows us to treat the economy as comprising of a representative household and a representative firm. An equilibrium consists of stochastic sequences of prices and quantities, such that:

1. Taking prices and monetary policy as given, households maximize their expected lifetime utility, subject to their constraints.

2. Taking prices as given, final goods firms maximize profits subject to their constraints.

3. Intermediate goods producers choose the price that maximizes their profits subject to their constraints.

[5] A bar denotes a steady state value.

4. The monetary authority follows its money growth rule and satisfies its budget constraint.

5. In addition to aggregate consistency, the aggregate resource constraints hold and the capital, goods, labor and money markets clear.

To ensure the existence of a time-invariant decision rule, all variables need to be stationary. We abstract from exogenous steady state growth for the real variables since that would have small effects on our results. However, note that this model would be the detrended version of the same economy with exogenous technical progress and the discount factor adjusted for the growth rate. Nominal variables are detrended with nominal money balances, i.e. we assume that the nominal money growth rate is stationary.

To find the decision rules, we use a numerical algorithm suggested by Uhlig (1999). This algorithm amounts to loglinearizing the equilibrium conditions around the steady state and then numerically solving the model by the method of undetermined coefficients.

2.5 Calibration

Rather than calibrating the model to a specific economy we take standard values from the literature and make sensitivity analysis. The parameter values for the benchmark calibration are taken from Smets and Wouters (2002). Those values are essentially equal to, for example, Cooley and Prescott (1995). Capital's share of output, θ_1 and θ_2, is set equal to 0.35 in both sectors. The deprecation rate, δ, is set equal to 0.1 and the effective discount factor, β, is set to 0.96. We assume that one period equals a year. We set the average markup in sector 1, μ_{ν_1}, equal to 1.2.

We set α so that the average time an agent spends in employment is 1/3 of total time. This is about the average time people between 18-64 years spend in employment, see Juster and Stafford (1991). The households' weight in the utility function on good 1 relative good 2 is assumed to be the same, i.e. $\alpha_1 = 0.5$.

To pin down the fixed cost, χ, we assume that profits are zero on average

$$\chi = \left(1 - \frac{1}{\nu}\right)(\bar{K}_1)^{\theta_1}(\bar{H}_1)^{1-\theta_1}. \tag{31}$$

The markup, ν, is assumed to follow an exogenous AR-process in the following way

$$\nu_t = (1-\rho)\mu_\nu + \rho\nu_{t-1} + \varepsilon_t \qquad \varepsilon \sim N(0, \Sigma), \tag{32}$$

where ρ measures the persistence of the shock and μ_ν the average markup. The parameter values are summarized in Table 1.

2.5.1 The monetary policy rule

The data is taken from Gerlach and Svensson (2002) and consists of quarterly observations of the EMU-wide aggregates of the money stock (M3), the CPI and the real GDP.[6] We use data starting in 1992, since at that time inflation targeting started to emerge as a candidate for monetary policy, and transform all variables into annualized quarterly growth rates.[7] Ultimately, we are interested in calibrating the monetary policy rule in (29). The unconditional correlations of these three variables are shown in Table 2.

Hence, in the data we find a positive correlation between money growth and inflation. However, the model presented in this paper contains two causal relations between money growth and inflation. First, an increase in the money growth leads to higher inflation, and second, a higher inflation rate leads to a monetary contraction. Since the monetary policy rule concerns the second of these causal relations we cannot parametrize the monetary policy rule by using the unconditional correlations. Rather, we need to disentangle the two causal relations between money growth and inflation. To do this we first estimate a VAR(8) consisting of the money growth, CPI-inflation and real GDP growth, since the data favors eight lags for the residuals to pass the Portmanteau test for autocorrelation in the residuals. We then conduct impulse responses to the estimated VAR. The accumulated responses to a one unit shock to the reduced form residuals are shown in Figure 1.

First, note that the impulse responses can disentangle the two causal relations mentioned above, and the responses have the correct sign; that is, an increased money growth leads to a higher inflation rate whereas a higher inflation rate is followed by a monetary contraction. Also note that monetary policy has accommodated higher GDP growth during the time period.

We use the accumulated response of money growth to inflation and GDP growth shocks to parametrize the monetary policy rule. Since our theoretical model is an annual model but the data is quarterly, we use the accumulated response after four periods in our monetary policy rule. This gives our benchmark

[6] Data prior to the formation of EMU is constructed as weighted averages across the countries, where a country's share of nominal GDP is used as weights.

[7] That is, for a variable X we compute the growth rate of that variable as $4 \cdot \Delta \ln X_t$.

calibration of the monetary policy rule as

$$g_t = \bar{g} \left(\frac{\pi_t^{CPI}}{\bar{\pi}} \right)^{-0.52} \left(\frac{Y_t}{Y_{t-1}} \right)^{0.44} \tag{33}$$

3 Price indices

The focus of this paper is on the effect of variations in the markup on nominal prices. We therefore need to define a nominal price index. There are numerous ways to do this. The most commonly used price index is the CPI. However, we also report results from a second measure, which we call the optimal nominal price index. To define this index, we draw upon the work by Obstfeld and Rogoff (1996), who define a consumption-based price index as

$$\begin{aligned} p_t^c &= \min \kappa_t & (34) \\ \text{s.t. } \tilde{c}_t &= 1, \end{aligned}$$

where p^c denotes the consumption-based price index, κ the consumption expenditure and $\tilde{c}$ an aggregate of consumption and leisure. The consumption aggregate is given by

$$\tilde{c}_t = \left[(c_{1,t})^{\alpha_1} (c_{2,t})^{(1-\alpha_1)} \right]^{\alpha} [\ell_t]^{(1-\alpha)}, \tag{35}$$

and the consumption expenditure by

$$\kappa_t = c_{1,t} + p_2 c_{2,t} + w_t \ell_t. \tag{36}$$

The solution is (neglecting a constant term)

$$p_t^c = \left(p_{2,t}^{1-\alpha_1} \right)^{\alpha} w_t^{1-\alpha}. \tag{37}$$

Defined this way p^c measures the units of a numeraire (say, good 1) necessary in a particular time period to purchase one optimal consumption-bundle consisting of all goods. We refer to this price index as an optimal real price index, since it measures the real price (units of good 1) of one unit of the optimal consumption basket. Note that this price index is defined for any given period of time.[8] It also includes the wage rate in addition to the relative price of the

[8] An alternative would be to define lifetime consumption as one consumption basket, which would give us a different price index. Defining lifetime consumption as one consumption basket is one way of justifying why a central bank may want to think about stabilizing asset prices, since asset prices in some models measure the price of future consumption in terms of current consumption.

two consumption goods. That an optimal price index for an inflation targeting central bank should include the wage rate has recently been suggested by Mankiw and Reis (2002). However, their motivation and theoretical framework is rather different from ours.

The real consumption-based price index measures how many units of good 1 that buys one optimal consumption basket consisting of consumption goods and leisure. Since p^m measures the nominal price of good 1, an optimal *nominal* price index, p^*, can then be defined as

$$p_t^* = p_t^m p_t^c. \tag{38}$$

The optimal nominal price index thus measures the nominal price of one optimal consumption basket.

The most common price index in practice is the CPI. The CPI measures inflation as a weighted average of the nominal price changes of the different goods. In terms of our model CPI-inflation would be calculated as

$$\pi_t^{CPI} = \omega \pi_t^m + (1 - \omega) \left[\pi_t^m + \Delta \ln p_{2,t} \right], \tag{39}$$

where ω is the weight placed on good 1 in the CPI. We determine the weight in the following way

$$\omega = \frac{\bar{c}_1}{\bar{c}_1 + \bar{p}_2 \bar{c}_2}, \tag{40}$$

that is, the weight is set to equal the steady-state expenditure share of good 1.Note that the CPI coincides with the optimal price index if the households do not derive any utility from leisure and the aggregation of the consumption goods is Cobb-Douglas (which we assume). In the quantitative analysis we will compare the optimal price index to the CPI.

4 Quantitative analysis

This section quantitatively investigates the relationship between the markup and the inflation rate in the model. This analysis consists of impulse response analysis and calculation of correlations between the inflation rate and the markup. Since the markup is exogenous we can actually say something about causality; that is, it is changes in the markup that cause changes in the inflation rate and not the other way around. We set the parameter values to the benchmark calibration and make sensitivity analysis with respect to the monetary policy rule.

4.1 Impulse response analysis

The impulse response analysis shows the quantitative effect on the inflation rate of an exogenous shock to the markup. In all experiments we will study the effect of a 1 percent negative shock to the markup. This analysis provides some intuition of the mechanisms at work in the model. All variables in the figures are measured as growth rates in percentage points, that is,

$$\gamma_{t,p_2} = 100\,(1-\omega)\left(\frac{p_{2,t}}{p_{2,t-1}} - 1\right), \tag{41}$$

$$\gamma_{t,p^c} = 100\left(\frac{p_t^c}{p_{t-1}^c} - 1\right), \tag{42}$$

$$\pi_t^* = 100\left(\frac{p_t^*}{p_{t-1}^*} - 1\right), \tag{43}$$

and the growth rate of the nominal price of good 1 is defined as

$$\pi_t^m = 100\left(\frac{p_t^m}{p_{t-1}^m} - 1\right). \tag{44}$$

The focus is on how monetary policy affects the correlation between the inflation rate and the markup. We therefore consider three different monetary policy rules. In the first example the money growth rate is simply given by

$$g_t = \bar{g}. \tag{45}$$

This is a natural benchmark since there is no endogenous response of monetary policy in this case. Another reason for studying this rule is that it is widely used in monetary analysis, see for example Cooley and Hansen (1989) and Cooley (1995).

Figure 2 shows the result of a persistent negative shock to the markup. The increased competition in sector 1 leads to a decrease of the relative price of good 1; that is, γ_{p_2} increases. This increases demand for good 1 and decreases demand for good 2. Aggregate consumption increases though. Since aggregate consumption rises and money growth is constant, π^m falls. What happens to the CPI? Remember that the CPI is composed of a nominal component, π^m, and a real relative price component, γ_{p_2}, which means that the total effect is unclear. However, quantitatively the fall in the monetary price dominates the relative price effect and the CPI falls.

What is the effect on the optimal price index of the decreased markup? The optimal price index includes, in addition to the relative price between good 1 and good 2 and the nominal price of good 1, the real wage. The increased competition lowers the firm's markup over marginal cost and hence increases the real wage. The increase in the real wage implies that the optimal price index rises initially.

Monetary policy will generally respond to the state of the economy, in particular it will respond to the inflation rate. We therefore consider an inflation targeting rule where the money growth rate responds to deviations of the current inflation rate from a target value. Formally, we assume the following rule

$$g_t = \bar{g}\left(\frac{\pi_t}{\bar{\pi}}\right)^{-0.52}. \tag{46}$$

That is, the monetary authority decreases money supply when inflation is above the inflation target $\bar{\pi}$ and increases the money supply when it is below the target. The monetary authority may respond to either the CPI or the optimal price index. In Figure 3a we show the results when the monetary authority responds to the CPI, i.e. $\pi_t = \pi_t^{CPI}$ and in Figure 3b the monetary authority responds to the optimal index, $\pi_t = \pi_t^*$.

Results are as expected. The CPI moves less when CPI is the target (policy more expansionary). When the optimal index is the target that index moves less (policy more contractionary).

In the final example, we assume that the monetary authority, in addition to the inflation rate, also responds to the growth rate of aggregate GDP; that is,

$$g_t = \bar{g}\left(\frac{\pi_t^{CPI}}{\bar{\pi}}\right)^{-0.52}\left(\frac{Y_t}{Y_{t-1}}\right)^{0.44}. \tag{47}$$

With this policy rule, money growth is accommodating deviations of output from steady state. That is, if output is temporarily high this means that also money growth is temporarily high. Potentially, this may stabilize the inflation rate since higher output leads to lower inflation, all else equal.

In Figure 4 we show the results. Since the decrease of the markup leads to a boom in output the monetary authority increases the money growth rate. As expected, this leads to higher inflation rates. In fact, both of our inflation measures are above steady state initially and are only slightly below the steady state during the transition back to steady state.

These examples have illustrated how the relationship between inflation and markups depend on monetary policy. The correlation may be positive or negative depending on the policy rule. In particular, the weight the monetary authority puts on output is crucial. This is formally quantified in the next subsection.

In some models of monetary policy it is "optimal" for an inflation targeting central bank to respond to output since it is assumed to be a good predictor of future inflation, see for example Svensson (1997). The transmission mechanism in our model is somewhat different though. As just illustrated, it is therefore possible that responding to output may not stabilize inflation.

4.2 Simulation results

We formally quantify the relationship between the inflation rate and the markup by calculating the correlation between the two variables under the benchmark calibration and different policy rules. The only shock to the economy is a persistent negative shock to the markup; the AR(1)-coefficient is 0.95. We calculate the correlation between the markup and CPI-inflation and between the markup and the change in the optimal price index. The results are shown in Table 3. Under the benchmark policy rule the correlation coefficient is slightly positive, 0.13, when inflation is measured by CPI and slightly negative, -0.15, when inflation is measured by the optimal index. The reason why the inflation rate increases when measured by the optimal index is due to the increase in the wage rate. From a policy perspective the results indicate that if the monetary authority follows a rule that both responds to inflation deviations from a target and accommodates output growth the effect of increased competition on the inflation rate is small.

Let us now study what happens if the monetary authority would follow a constant money growth rule. In this case we get the maybe expected result that increased competition leads to lower inflation. Both of our inflation measures lead to lower inflation, this relationship is particularly strong for the CPI. What if the monetary authority would follow an inflation targeting rule? As can be seen in Table 3 this has a very small effect on the correlation if we compare to the result from the constant money growth rule. This is true irrespectively of which price index that is included in the reaction function.

By letting the monetary authority also accommodate output the correlation changes quite dramatically. If the weight on output is high enough the correlation is actually negative for both measures of inflation, which is illustrated in the example where $\varpi_Y = 0.8$. That is, an increase in competition leads to higher inflation. Notably, the correlation between the optimal nominal price index and the markup shock is negative for all three values on the weight on output.

These results highlight the fact that the correlation between changes in competition and inflation ultimately depends on monetary policy. In particular, the extent to which the monetary authority accommodates output matters. An inflation targeting central bank that does not accommodate output fluctuations will actually give rise to a quite strong positive correlation between markups and inflation (CPI).

To study how sensitive the results are to the benchmark calibration we perform sensitivity analysis with respect to all parameter values. The results are reported in Table 4. We do not report results from changes in β, δ and α since they hardly affect the relationship at all. Actually, the correlation is rather robust to changes in basically all parameter values. Our main finding that the correlation between markup shocks and inflation is slightly positive when measured by the CPI and slightly negative when measured by the optimal price index is true for all parameter values we report result from.

5 Conclusions

We have quantified the correlation between persistent changes in the markup in one sector of the economy and the inflation rate. Two measures of inflation have been used; the CPI and an optimal nominal price index that includes the wage rate. How this correlation is affected by monetary policy has also been quantified.

The correlation between changes in the markup and CPI-inflation is in general positive under an exogenous money growth rule as well as under an inflation targeting rule. That is, a decrease of the markup leads to a decrease in the CPI-inflation rate. However, if inflation is measured by the optimal nominal price index the correlation is slightly negative. That is, a decrease in the markup will lead to higher inflation rates because of higher wages.

The relationship is sensitive to whether the policy rule includes an output term. If monetary policy accommodates output strongly the correlation will be negative. A decrease in the markup then leads to higher inflation, as measured by both the CPI and the optimal nominal price index. The reason for this, perhaps surprising result, is that the lower markup leads to higher output which induces the monetary authority to raise the money growth rate, which in turn leads to higher inflation.

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Table 1. Benchmark calibration.

Parameter	Description	Value
α	Weight on consumption relative to leisure	0.38
α_1	Weight on good 1 relative to good 2	0.50
β	Discount factor	0.96
δ	Depreciation rate	0.10
$\theta_1 = \theta_2$	Capital share	0.35
$\bar{g}$	Growth rate of money in steady state	1.02
ϖ_π	Weight on inflation target in monetary policy rule	-0.52
ϖ_Y	Weight on output growth in monetary policy rule	0.44
ρ	AR(1) parameter on markup	0.95
μ_ν	Average markup	1.20

Table 2. Unconditional correlations in the data.

	$\frac{Y_t}{Y_{t-1}}$	π_t	g_t
$\frac{Y_t}{Y_{t-1}}$	1	-0.45	-0.45
π_t	-0.45	1	0.26
g_t	-0.45	0.26	1

Table 3. Correlations under benchmark calibration and different policy rules.

	$\bar{g}\left(\frac{\pi_t}{\bar{\pi}}\right)^{-0.52}\left(\frac{Y_t}{Y_{t-1}}\right)^{0.44}$	$\bar{g}$	
$\rho_{\nu_t,\pi_t^{cpi}}$	0.13	0.52	
ρ_{ν_t,π_t^*}	-0.15	0.07	
	$\bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.2}$	$\bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.5}$	$\bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.8}$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.51	0.50	0.49
ρ_{ν_t,π_t^*}	0.00	-0.08	-0.13
	$\bar{g}\left(\frac{\pi_t^*}{\bar{\pi}}\right)^{-0.2}$	$\bar{g}\left(\frac{\pi_t^*}{\bar{\pi}}\right)^{-0.5}$	$\bar{g}\left(\frac{\pi_t^*}{\bar{\pi}}\right)^{-0.8}$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.52	0.52	0.52
ρ_{ν_t,π_t^*}	0.07	0.06	0.06
	$\bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.5}\left(\frac{Y_t}{Y_{t-1}}\right)^{0.2}$	$\bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.5}\left(\frac{Y_t}{Y_{t-1}}\right)^{0.5}$	$\bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.5}\left(\frac{Y_t}{Y_{t-1}}\right)^{0.8}$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.33	0.09	-0.03
ρ_{ν_t,π_t^*}	-0.12	-0.16	-0.18

Table 4. Sensitivity analysis given benchmark policy rule $g_t = \bar{g}\left(\frac{\pi_t^{cpi}}{\bar{\pi}}\right)^{-0.52}\left(\frac{Y_t}{Y_{t-1}}\right)^{0.44}$.

	$\alpha_1 = 0.2$	$\alpha_1 = 0.5$	$\alpha_1 = 0.8$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.15	0.13	0.12
ρ_{ν_t,π_t^*}	-0.15	-0.15	-0.15
	$\theta_1 = 0.25$	$\theta_1 = 0.35$	$\theta_1 = 0.45$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.20	0.13	0.08
ρ_{ν_t,π_t^*}	-0.13	-0.15	-0.17
	$\theta_2 = 0.25$	$\theta_2 = 0.35$	$\theta_2 = 0.45$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.10	0.13	0.11
ρ_{ν_t,π_t^*}	-0.15	-0.15	-0.15
	$\mu_{\nu_1} = 1.05$	$\mu_{\nu_1} = 1.20$	$\mu_{\nu_1} = 1.35$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.08	0.13	0.18
ρ_{ν_t,π_t^*}	-0.15	-0.15	-0.15
	$\mu_{\nu_2} = 1.05$	$\mu_{\nu_2} = 1.20$	$\mu_{\nu_2} = 1.35$
$\rho_{\nu_t,\pi_t^{cpi}}$	0.12	0.08	0.07
ρ_{ν_t,π_t^*}	-0.15	-0.16	-0.16

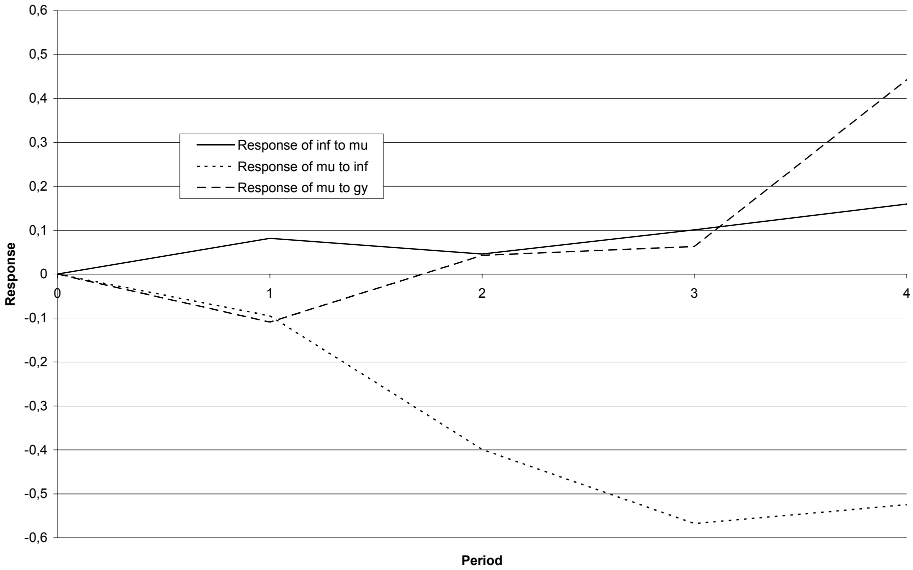

Figure 1: Accumulated responses from the estimated VAR-model.

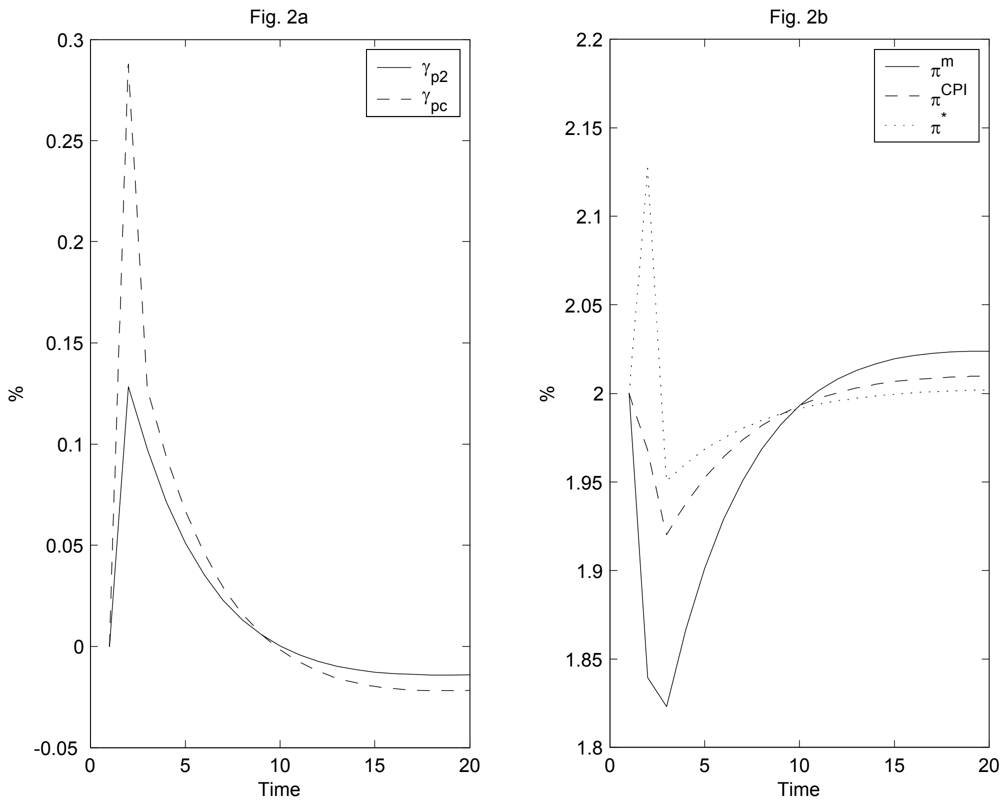

Figure 2: Responses to a 1 percent decrease in the markup under a constant money growth rule.

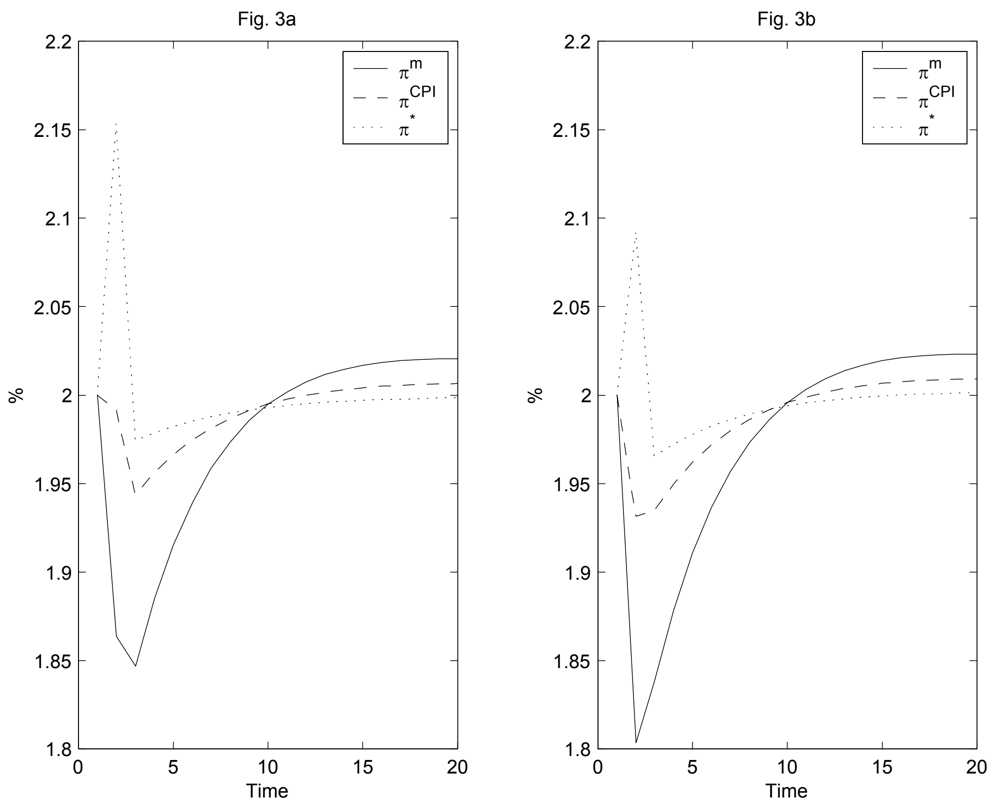

Figure 3: Responses to a 1 percent decrease in the markup under an inflation targeting rule.

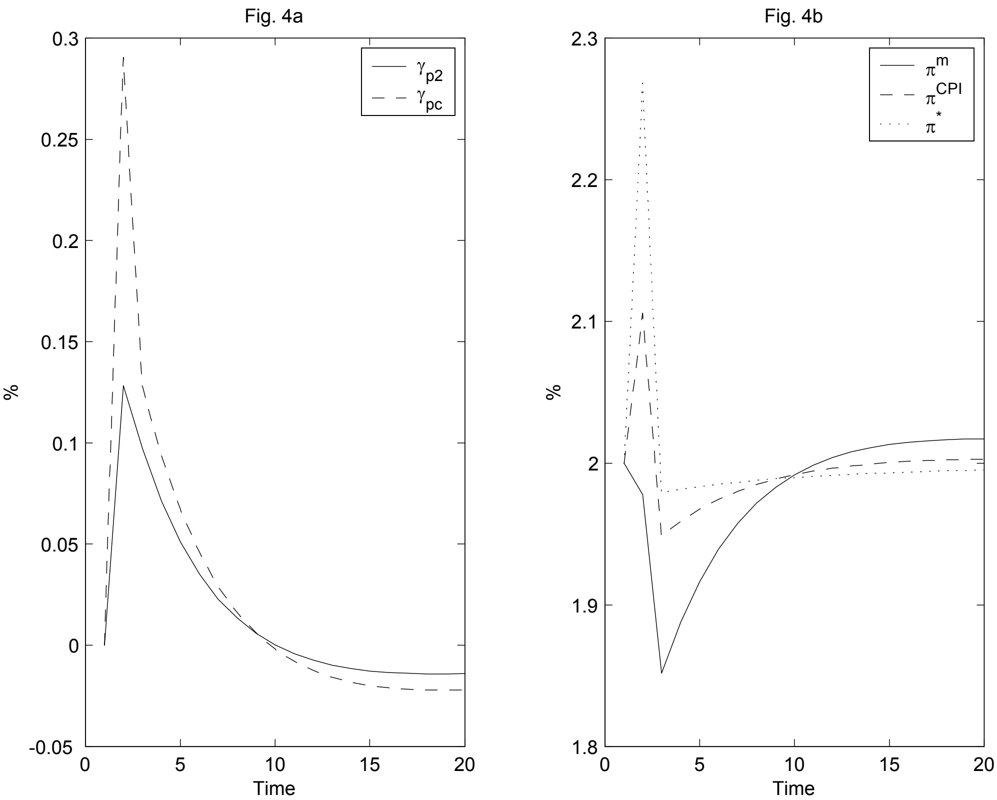

Figure 4: Responses to a 1 percent decrease in the markup under an inflation targeting rule that also accommodates output.

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Sveriges Riksbank
Visiting address: Brunkebergs torg 11
Mail address: se-103 37 Stockholm

Website: www.riksbank.se
Telephone: +46 8 787 00 00, Fax: +46 8 21 05 31
E-mail: registratorn@riksbank.se

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