IS THERE A COST CHANNEL OF MONETARY POLICY TRANSMISSION? AN INVESTIGATION INTO THE PRICING BEHAVIOUR OF 2,000 FIRMS

by Eugenio Gaiotti* and Alessandro Secchi*

Abstract

The paper exploits a unique panel, covering some 2,000 Italian manufacturing firms and 14 years of data on individual prices and individual interest rates paid on several types of debt, to address the question of the existence of a channel of transmission of monetary policy operating through the effect of interest expenses on the marginal cost of production. It has been argued that this mechanism may explain the dimension of the real effects of monetary policy, give a rationale for the positive short-run response of prices to rate increases (the "price puzzle") and call for a more gradual monetary policy response to shocks. We find robust evidence in favour of the presence of a cost channel of monetary policy transmission, proportional to the amount of working capital held by each firm. The channel is large enough to have non-trivial monetary policy implications.

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Keywords: monetary transmission, cost channel, working capital.

Contents

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1. Introduction[1]

A growing literature has addressed the possibility that monetary policy actions do not only affect aggregate demand, but also exert an influence on economic variables through the supply side; namely, they influence firms' interest expenses on working capital and, as a consequence, marginal costs of production and output prices.

The implications of such a conjecture are far reaching. The most apparent is that in the short run an increase in interest rates may cause prices to rise, rather than to fall. The possibility that monetary policy shares some of the features of a supply shock would also help to explain the large and persistent effects of monetary policy on the real economy. Last but not least, the existence of this effect may also have important consequences in the design of optimal policies, as it is likely to imply a worsening of the short-run output-inflation trade-off and to call for a more gradual stabilization of inflationary shocks.

However, empirical evidence in favour of this hypothesis is not abundant and remains controversial. Virtually all of it is based on aggregate - sometimes sectoral - data and, in particular, on the identification of a short-term positive response of aggregate prices to interest rate shocks. It is well known that macro-evidence regarding the effects of monetary shocks is subject to substantial identification and specification problems and, consequently, to considerable uncertainty of interpretation. The issue, therefore, is not yet settled.

This paper's contribution is to exploit the rich information from a unique micro-dataset of Italian manufacturing firms, covering 14 years and about 2000 firms, which, most notably, includes firm-specific data on changes in output prices and on the interest rate paid on debt. The availability of disaggregated information helps us to make important advances with respect to the existing empirical literature, avoiding the identification problems typical

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of time-series estimates. By exploiting cross-section variability in output prices and interest expenses we are able to disentangle firm-specific cost channel effects from demand effects, which are aggregate in nature. Moreover, the availability of firm-level information on those variables which affect the existence of a cost channel enables us to construct supplementary and sharper tests for the existence of the cost channel.

Our analysis, based on firm-level data, identifies a significant effect of interest expenses on firms' prices. The established hypothesis that this effect is linked to the role of working capital in the production process of the firm, i. e. to a temporal mismatch between factor payments and sales receipts (Hicks, 1979, Christiano, Eichenbaum and Evans, 1997 and Barth and Ramey, 2001), cannot be rejected. On the basis of the properties of standard theoretical macro-models which feature a cost channel, we judge the size of this supply-side effect to be large enough to warrant careful consideration in the design of monetary policy.

The paper is organized as follows. Section 2 reviews the literature on the supply effects of monetary policy and sets out the specific contribution of this paper. Section 3 derives a price equation in which the interest rate is allowed to affect the marginal cost of producing output. This equation forms the basic specification to be used in the estimation stage. Section 4 presents the main features of our dataset. The main empirical results and some extensions are reported in sections 5 and 6. Section 7 concludes.

2. The effects of monetary policy on production costs

2.1 Implications

The idea that interest expenses should be treated as a cost of production is a long-standing one. The argument that a decrease in interest rates determines a reduction in prices via lower costs of production was already advanced in 1844 by Thomas Tooke, leading scholar of the "banking school".[2] Hicks (1979) argues that the short-term interest rate should be regarded as the price of a particular factor of production (in addition to capital and labour), which he labels "waiting time" or "intertemporal switch in output".

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[2] See the survey by Ginzburg and Simonazzi (1997).

Seelig (1974) reports a famous version of the view that the interest rate affects costs of production, expressed by US congressman Wright Patman, chairman of the Joint Economic Committee, who in March 1970 argued that raising interest rates to fight inflation was like "throwing gasoline on fire". Goodhart (1986, p. 96) recounts the opinion of "British businessmen", who "still tend to regard interest rates as a cost and look to establish a price *rise* in response to increased interest rates". More recently, Evans (2001) quotes anecdotal information collected by Federal Reserve staff in times of rising interest rates, about the passing over of increasing inventory costs to prices. Similar arguments were also prominent in the debate on monetary policy and inflation in Italy in the 1970s. Andreatta (1973, p. 348), quoting Grant (1972), advances the argument that a credit restriction can contribute to inflation when it bears on the supply side, limiting the financing of working capital. Valli (1979, p. 146) argues that an increase in interest rates introduces inflationary pressures in the economy by increasing the firms' cost of capital.

Barth and Ramey (2001) revive the argument that monetary policy may operate in the short run through a cost channel (while in the longer run the demand channel dominates, consistently with money neutrality). They argue that monetary policy shocks affect the short-run productive capacity of the economy by shifting both the demand and supply functions in the same direction, and that this mechanism may help to explain three empirical regularities not well accounted for by standard theories: the degree of amplification and persistence of the real effects of monetary shocks, the empirical finding that the price level rises in the short run in response to a monetary tightening ("price puzzle") and the fact that, in the short run, the responses of the main macroeconomic variables to a monetary shock are more similar to those due to a technology shock than to a demand shock.[3]

According to Barth and Ramey, the cost channel is based on an active role of net working capital (inventories, plus trade receivables, less trade payables) in the production process and on the fact that variations in interest rate and credit conditions alter firms' short-run ability to produce final output by investing in net working capital. This effect may be modeled by directly assuming that inventories or working capital enter the production

[3] They present evidence showing that productivity and real wages fall after an adverse productivity shock or a restrictive monetary shock; in contrast, they rise after a negative demand shock.

function (Ramey, 1989 and Ramey, 1992) with the interest rate being the price of such a factor. Alternatively, a temporal mismatch between factor payments and sales receipts may be explicitly modeled: Christiano, Eichenbaum and Evans (1997) show that, in a model where output is produced only through labour and where the purchase of production factors must be financed through borrowing, the marginal cost of labour is equal to the wage times the gross nominal interest rate. [4] Interest rates affect production costs also in the models by Farmer (1984) and Christiano and Eichenbaum (1992). Another strand of literature links the existence of a credit channel of monetary transmission to supply-side effects of monetary policy, arguing that, due to the latter, tighter monetary policy may be inflationary (Stiglitz and Greenwald, 2003, p.155). [5]

The existence of a cost channel can alter the optimal course of monetary policy in the face of various shocks, possibly in a substantial way. Ravenna and Walsh (2003) derive a cost channel effect in a new-Keynesian framework based on optimizing behaviour, again assuming that wages are paid in advance. They show that, under this assumption, an inflation-output trade-off arises even after productivity or demand disturbances and conclude claiming that optimal policy calls for more gradualism in the stabilization of the inflation rate. Under the assumption that all variable costs of production are paid one quarter in advance, the optimal policy response to an adverse shock on prices needs to be much more gradual. It can be shown that in their model, in the case of a cost-push shock it may even be an interest rate easing, as the central bank can in part offset the adverse cost-push shock by decreasing rates, thus relieving firms from interest expenses on their working capital. [6] However, the actual relevance of this conclusion crucially depends on the quantitative magnitude of the effect of interest rates on marginal costs.

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[4] A different strand of literature concentrates on the effect of tighter liquidity constraints on prices through mark-ups, rather than through marginal costs (Chevalier and Scharfstein, 1996; on Italian firms, Bottasso, Galeotti and Sembenelli, 1997)). Barth and Ramey (2002) stress the similarities with the cost channel hypothesis.

[5] Fiorentini and Tamborini (2001) also emphasize the potential connection between credit conditions and firms' production activity as the missing link in the credit channel literature.

[6] The point is illustrated in Appendix I.

2.2 Existing evidence

Even if the cost channel is becoming a common building block in general equilibrium macro models, the empirical evidence regarding its existence and relevance is still limited and mainly based on the identification of a short-run positive effect of interest rate increases on aggregate, or sectoral, price levels. Seelig (1974) , based on two and three-digit industry data and on the assumption of mark-up pricing above average unit costs, argued that in the 1950s and the 1960s the impact of interest rate changes on prices was fairly negligible. More recently, Barth and Ramey (2001) provide evidence in favour of the existence of a cost channel in the US over the last forty years, showing that after a restrictive monetary policy shock the price/wage ratio increases (and productivity decreases) in a vector auto-regression. The latter finding is stronger in those (two-digit) industries that feature larger interest expenditures as a share of sales. Ravenna and Walsh (2003) estimate a stylized general equilibrium model for the US and find that the cost channel exerts a statistically and economically significant role in determining price and output dynamics: a one percent increase in (quarter-on-quarter) interest rates affect the marginal cost of production by about 1 point. However, in a similar setting Rabanal (2003) obtains a much smaller value of the cost channel coefficient.

Yet, there are a few shortcomings that affect more or less directly the results presented so far in the literature. It has been repeatedly shown that the empirical finding of a positive correlation between interest rate and prices, known as the "price puzzle", is not necessarily related to a structural relationship but could simply reflect the central bank's reaction function (Sims, 1992) and the omission of some relevant variable from the analytical framework (Christiano, Eichenbaum and Evans, 1994 and Balke and Emery, 1994); as a consequence, the main empirical building block of the cost channel conjecture rests on shaky ground.[7] More generally, the need to disentangle the effects of interest rates on the supply side from those on the demand side and the need to take into account the effect of output and prices on interest rates via the reaction function poses complex identification problems, which may also affect the estimation of GE models, so that estimates based on aggregated data are likely to provide inconclusive evidence of the magnitude of the cost channel effect.

This seems to be confirmed by the conflicting evidence reported by various authors. Even if in principle one could construct empirical frameworks that would allow for cleaner tests of the existence of the cost channel, in most of the cases these should be based on the use of variables that, at the aggregate level, are either not available or lack the degree of intertemporal variability needed to identify cost channel effects. Working capital is one example of such variables.

The strategy we adopt to get rid of the shortcomings that plague time-series estimates is based on the observation that the main difference between the demand channel and the cost channel is that the former is intrinsically aggregate (or sectoral) while the latter, being based on the amount of working capital owned by each firm and on its specific interest rate, is an individual effect. This implies that a direct way to search for an effect of interest rate changes on firms' pricing policies is to inspect individual output price responses to interest rate changes once all aggregate effects (including traditional monetary policy transmission through demand) and variations in material and labour costs are controlled away through, respectively, appropriate dummies and firm-level information on variations in input costs. This approach has so far been constrained by data limitations and in particular by lack of information on firm-level prices and interest rates. We exploit the possibilities offered by the availability of a unique firm-level dataset (discussed in detail in Section 4) which includes firm-specific information on annual changes in the price of output, as well as on interest rates and on the importance of working capital. The availability of firm-level data is particularly appealing for different reasons. First, it allows testing for the existence of a positive relationship between individual changes in interest rates and individual changes in output prices which, once aggregate effects are controlled for, might be interpreted as a condition for the existence of the cost channel. Second, taking advantage of firm-level information on both interest rates and on the weight of working capital in the production process, we are able to test for the relevance of the determinants of the cost channel discussed by Barth and Ramey (2001). Finally, further information available in our dataset, such as the frequency of price revisions by individual firms, allows us to perform several robustness tests of our conclusions.

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[7] See also Gilchrist (2001) and Evans (2001).

Our strategy consists of two steps. First we derive a firm-level price equation that allows for a direct effect of interest rates on prices. Then we estimate a set of alternative empirical specifications of this equation to test for the existence of the cost channel.

3. A price equation with a cost channel

We derive a standard price equation in the spirit of Bils and Chang (2000), assuming a production technology that uses labour, capital and material inputs. Output prices are set in a framework of monopolistic competition, as a mark-up over marginal costs, while the firm behaves as a price-taker on the factor market. Material inputs are included to allow for the role of working capital: we impose that a fixed fraction of these inputs must be held as inventories and financed. We also assume that a fraction of labour inputs must be paid in advance and externally financed.

Output is produced according to: [8]

$$y_t = A_t M_t^{\delta} N_t^{\beta} K_t^{\alpha} \tag{1}$$

where A_t reflects technology, M_t is material input, K_t is capital, N_t is labour.

A cost channel is introduced by assuming that labour and material inputs must be paid in advance and have to be financed at an interest rate equal to r_t. More specifically, we assume that in each production period the firm must hold a fixed proportion k_M of material inputs as working capital (inventories less net commercial debt)[9] and pay a fixed proportion, k_N, of the wage bill before receiving the labour services. The latter assumption is included

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[8] The price equation derived in this section does not require constant return to scale (the assumption of market power ensures that second order conditions are met anyway). We adopt a Cobb-Douglas specification for the sake of simplicity; similar results could be obtained with more general functional forms, as in Bils and Chang (2000), or even assuming that capital is a fixed factor in the short run, as in Christiano, Eichenbaum and Evans (1997).

[9] The assumption of a fixed k_M is made for the sake of analytical simplicity. It could alternatively be assumed that inventories directly enter the production function, implying that their demand is inversely related to interest rates. It can be shown that this would not substantially alter the marginal cost equation (4) in a neighbourhood of equilibrium.

because it is widely used in the theoretical literature; however, it is not essential, as it can be dropped without affecting the overall results.[10]

Denoting the prices of material inputs, labour and capital respectively as v, w and c, and the interest rate paid to finance working capital and anticipated wages as r_t, total costs are given by:

(2) $$C_t = v_t M_t (1 + k_M r_t) + w_t N_t (1 + k_N r_t) + c_t K_t$$

Building on first order conditions of the cost minimization problem, and defining $\gamma = \delta/(\delta + \alpha + \beta)$, the log-change in the marginal cost (a dot above a variable indicates log-variations) is equal to:[11]

(3) $$\dot{MC}_t = (1-\gamma)\dot{w}_t + \gamma\dot{v}_t - [\dot{y}_t - (\gamma\dot{M}_t + (1-\gamma)\dot{N}_t)] + h\Delta r_t + (1-\gamma)k_N \Delta r_t$$

where we defined $h \equiv \gamma k_M$ and simplified out the user cost of capital c_t.[12] The price equation is then obtained by equating the change in price to the change in marginal cost and change in mark-up.[13] The final price equation can be written in two equivalent ways:

(4) $$\dot{P}_t = \dot{\mu}_t + (1-\gamma)\dot{w}_t + \gamma\dot{v}_t - [\dot{y}_t - \gamma\dot{M}_t - (1-\gamma)\dot{N}_t] + h\Delta r_t + (1-\gamma)k_N \Delta r_t$$

(5) $$\dot{P}_t = \dot{\mu}_t + (1-\gamma)\dot{ULC}_t + \gamma\dot{UMC}_t + h\Delta r_t + (1-\gamma)k_N \Delta r_t$$

Equation (4) includes on the right-hand side the change in the interest rate, which enters in two interaction terms: multiplied by the working capital/total costs ratio(h) and multiplied by a term proportional to the value added/total costs ratio($1-\gamma$). Moreover, the

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[10] The assumption by Christiano, Eichenbaum and Evans (1997) that labour costs are anticipated for the whole production period corresponds, in our notation, to $k_N=1$.

[11] See Appendix II for details on the derivation. The change in marginal cost can also be written as:

$$\dot{MC}_t = (1-\gamma)\dot{w}_t + \gamma\dot{v}_t - \dot{TFP}_t + \alpha(\alpha+\beta+\delta)^{-1}(\dot{N}_t - \dot{K}_t) + h\Delta r_t + (1-\gamma)k_N \Delta r_t$$

This formulation, akin to the one used by Bils and Chang (2000), is written in terms of the change in total factor productivity (*TFP*) and a measure of the labour/capital ratio. For such a formulation to be empirically operational, an estimate of K is needed, whose derivation would go beyond the scope of this paper.

[12] Simplifying away c_t is convenient since direct measures of this variable are problematic and not central to the purpose of this paper. In (3), movements in the user cost of capital indirectly affect marginal cost by inducing movements in labour productivity.

[13] The implicit assumption is that firms adjust their price each period, which is not completely unrealistic

equation also includes the change in input prices and wages, as well as, in square brackets, a measure of the change in productivity, which is specified as a weighted average of the change in output per worker and the change in output per unit of input. The role of this term is threefold:[14] it captures the effect on prices of exogenous changes in productivity due to the term A_t, it measures the effect of movements in the user cost of capital c_t (which induce changes in the labour/capital and input/capital ratios) and, in the case of non-constant returns to scale, it also captures scale effects. Equation (5) is expressed directly in terms of the change in unit costs (unit material input cost, $U\dot{M}C_t \equiv \dot{y}_t - \dot{v}_t - \dot{M}_t$, and unit labour costs, $U\dot{L}C_t \equiv \dot{y}_t - \dot{w}_t - \dot{N}_t$), multiplied by the relevant shares.

From first order conditions, the parameter γ equals the share of material inputs costs over total costs: $\gamma=(v_t M_t\ (1+k_m r_t))/C_t$; consequently, the parameter h is approximately equal to the ratio between working capital and total costs C.

Equations (4) and (5) are mapped in two empirical specifications. The first one is:

$$(6)\quad \dot{P}_{i,t}=\dot{\mu}_t+a_1\left[(1-\gamma_i)\dot{w}_{s,t}\right]+a_2\left[\gamma_i\dot{v}_{s,t}\right]-a_3\left[\dot{y}_{i,t}-\gamma_i\dot{M}_{i,t}-(1-\gamma_i)\dot{N}_{i,t}\right]+a_4\left[h_i\Delta r_{i,t}\right]+a_5\left[(1-\gamma_i)\Delta r_{i,t}\right]+a_6\left[CU_{i,t}\right]$$

where sub-indexes '*s*' and '*i*' denote that a variable is measured, respectively, at a sectoral or at an individual level. In equation (6), $\dot{P}_{i,t}$ is the change in output price for firm i in period t; $\dot{\mu}_{s,t}$ is the time-varying change in the mark-up, measured by the inclusion of time-sector dummies, which also captures all aggregate effects on prices; $(1-\gamma_i)\dot{w}_{s,t}$ is the change in contractual wages in branch s (to which the firm belongs), times the value added/total costs ratio for firm i; similarly, $\gamma_i\dot{v}_{s,t}$ is the change in input prices in branch s times the share of material input over total costs in firm i; $\left(\dot{y}_{i,t}-\gamma_i\dot{M}_{i,t}-(1-\gamma_i)\dot{N}_{i,t}\right)$ is a measure of productivity change; $h_i\Delta r_{i,t}$ is the change in the firm-specific interest rate, times the firm-specific variable h_i, which is measured as the fraction of net working capital over total costs; $(1-\gamma_i)\Delta r_{i,t}$ interacts the change in the interest rate with the share of value added in total costs; this term is based on the assumption that the fraction of labour cost which have to be

given the annual frequency of our data. The issue is addressed in more detail in section 5.2.

[14] The term in square brackets may be written as $(\alpha+\beta+\delta)^{-1}[\dot{A}_t-\alpha(\dot{c}_t-\dot{w}_t)+(\alpha+\beta+\delta-1)\dot{y}_t]$.

anticipated (k_N) is constant across firms. $CU_{i,t}$ is a measure of capacity utilization in firm *i* at time *t*. The latter term, which does not appear in (4), is included to control for firm-specific changes in mark-ups.[15] We expect the estimated parameters a_1 - a_4 to be equal to 1, as suggested by equation (4), and a_5 and a_6 to be positive. We are in particular interested in the sign and size of coefficients a_4 and a_5, which measure the cost channel effect.

The second specification is:

$$(7) \qquad \dot{P}_{i,t} = \dot{\mu}_t + b_1\left((1-\gamma_i)U\dot{L}C_{i,t}\right) + b_2\left(\gamma_i U\dot{M}C_{i,t}\right) + b_3\left(h_i \Delta r_{i,t}\right) + b_4\left[(1-\gamma_i)\Delta r_{i,t}\right] + b_5 CU_{i,t}$$

where $(1-\gamma_i)ULC_{i,t}$ is the change in firm *i*'s unit labour cost, times the share of value added over total cost in the same firm and $\gamma_i UMC_{i,t}$ is the change in firm *i*'s unit material input cost times the share of material input cost over total cost. The other terms are the same as in (6). We expect coefficients b_1 - b_3 to be equal to one, as in equation (5), and b_4 and b_5 to be positive. Again, we are particularly interested in the sign and size of coefficients b_3 and b_4.

4. The data

The panel is obtained by combining information from three datasets: the Survey of Investment in Manufacturing (SIM, "*Indagine sugli investimenti delle imprese industriali*"), the Company Accounts Data Service (CADS, "*Centrale dei bilanci*") and the Italian Credit Register (CR, "*Centrale dei rischi*"); the latter source is only used in some of the regressions.

The SIM database includes individual information on Italian manufacturing firms since 1978. Data are collected at the beginning of each year by interviewing a stratified sample[16] of between 500 and 1000 firms with more than 50 employees. The first part of the survey

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[15] Domowitz, Hubbard and Petersen (1988) point out that there is a strong positive relationship between capacity utilization and market power. Marchetti (2002) provides evidence in favour of this positive relationship for Italian manufacturing firms. The inclusion of capacity utilization in the estimated equations can also represent a short-run, transitory effect of idle capacity on the pricing behaviour of the firm (Eckstein and Fromm, 1968). In our estimates, the results proved to be robust to the inclusion or exclusion of this variable.

[16] The sample is stratified according to three criteria: sector, size and geographical location. With regard to the first criteria the two digits ATECO91 classification of the National Institute of Statistics (ISTAT) is adopted. Size is proxied by the number of employees (four classes are evaluated: 50-99, 100-199, 200-999, 1000+). Location refers to a regional (19) disaggregation. The stratification methodology adopted (*optimal allocation to strata*) implies that in SIM larger firms and firms located in the south of Italy are somehow over-

includes qualitative and quantitative information on the corporate structure of the firm, employment, investment, current production and technical capacity. The second part covers specific topics that change year by year. An intense process of data revision is carried out by officials of the Bank of Italy. A special effort has been made to keep information as closely comparable as possible in subsequent years. Still, the dataset may be affected by some adverse self-selection bias since firms belonging to SIM are interviewed on a voluntary basis. For our purpose, a major advantage of SIM is the fact that it contains information on a number of variables that are not usually available. Very importantly, since 1988 it includes the average percentage change in output prices, which is one of the core variables in our analysis.

The CADS database contains detailed balance-sheet and profit and loss information on Italian non-financial firms. Data are collected by a consortium, which includes the Bank of Italy and all major Italian commercial banks interested in pooling information about their clients. Time series starting in 1982 are available in electronic format; the sample is currently composed of (around) 50,000 firms. A major advantage of CADS is that data undergo an accurate process of reclassification which ensures a good degree of comparability both across firms and time. However, the database does not include firms that have credit lines for an amount less than (about) 80,000 euros, that do not use their credit lines or that are insolvent, which may introduce an upward bias in the average creditworthiness of the firms belonging to CADS.

The Italian Credit Register (CR) is a database, housed at the Bank of Italy, which contains extensive information on loan contracts granted by Italian banks. All banks report information on credit granted and utilized for all loans in excess of a minimum threshold;[17] a subset of 80 banks also report the interest rate charged to individual borrowers, for different types of loans: commercial loans, personal loans, credit lines, foreign credit operations, collateralized loans, medium and long-term loans. Due to changes in the degree of coverage, we are currently in a position only to exploit CR for a shorter time span, starting in 1989.

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represented.

[17] The threshold was set at 80 million lire (41,300 euro) until 1995 and at 150 million lire thereafter. It is currently set at 75,000 euro.

During the last two decades, SIM, CADS and CR have been extensively used to investigate a large number of disparate topics. Only in the last few years have some authors started exploiting the possibilities provided by their joint use. Guiso and Parigi (1999) merge data on capital stock, income and cash flow (CADS) with data on effective and planned investment and on expected demand (SIM) to investigate the effects of uncertainty on the investment decision of a sample of Italian manufacturing firms. Marchetti and Nucci (2001) use data on employment and hours, labour compensation, investment and capital stock (SIM) and use them together with information on sales, inventory change, purchases of intermediate goods (CADS) to obtain a measure of technological change that is not affected by any source of procyclical productivity. Marchetti and Nucci (2002) merge the two datasets to obtain detailed statistics on the typical frequency of price revision of a sample of Italian manufacturing firms and to investigate whether different degrees of price stickiness affect how a technological shock influences the use of the labour input in the production process. Guiso, Kashyap, Panetta e Terlizzese (2002) use data from CADS and CR to investigate how estimates of the interest sensitivity of investment depend on alternative measures of the marginal financing costs of the firm.

Information on individual price changes only exists in SIM since 1988. The complete sample of SIM over the period 1988–2001, after excluding a few firms that do not belong to the manufacturing sector, includes 2724 firms (14,827observations). Attrition related to the merging with CADS and missing values reduce the initial sample to a set of 2192 firms (9751 observations).[18] Our sample is fairly representative of firms with more than 50 employees according to the geographical and to the sectoral composition; however, it is slightly biased toward larger firms (Tables 2 to 4).

Table 5 presents some basic statistics on the variables that are used in the empirical analysis.

The dependent variable, the *firm-level percentage change in the price of output* ($\dot{P}_{i,t}$), is drawn from SIM, based on a specific question.[19] The aggregate behaviour of this variable

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[18] In Table 1 we report the number of observations in each of the years of the final sample.

[19] Firms are asked to report the percentage change in the average price of goods sold, together with the nominal change in sales. To check the consistency of the responses, a control question asks to report the

tracks closely its macro equivalent: the correlation between its annual sample mean and the annual change in output prices in manufacturing (ISTAT) is around 0.9 (Figure 1).

A first measure of the *firm-level interest rate* ($r^{CR}_{i,t}$) is obtained directly from bank data, as the firm-specific lending rate on commercial borrowing and commercial paper discounted (CR), measured at end-year. This is an almost ideal variable for our purposes, as it matches the appropriate type of borrowing to finance working capital and it is measured quite precisely in the dataset. However, it is available over a shorter time interval than the rest of the sample (since 1989, or 1990 after taking first differences). [20]

As a robustness check, and to gain degrees of freedom, a second measure of the interest rate ($r^{CA}_{i,t}$) is constructed by dividing total interest expenses by total financial debt (CADS). This measure has the advantage of being available for a larger number of firms and for a longer time horizon. However, being computed *ex post* from balance sheet data which aggregate a large number of liabilities of the firm, it is likely to be subject to measurement errors; moreover, unlike the previous measure, it aggregates the interest rate paid on all types of borrowing.

A third measure is the average policy interest rate (r^{P}_{t}), i. e. the average annual Bank of Italy repo rate and the rate on ECB main refinancing operations since 1999. This measure is not firm-specific; the cross-sectional variability of the variable included in the regression is solely due to the interaction terms. When using this measure of the interest rate, the advantages of the micro-approach may be somehow diminished, although we may directly answer the question of the effects of policy moves on firms' pricing behaviour. The three measures are used alternatively to check robustness of the results. Through time, they behave consistently with each other (Figure 2).

Net working capital is constructed using data from CADS and it is defined, following Barth and Ramey (2001), as the value of inventories, plus commercial credit, less commercial debt. To obtain the ratio h_i, we divide net working capital by total operating

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variation in sales in real terms.

[20] To control for outliers, we first deleted observations below the 5th and above the 95th percentiles of the distribution of the interest rate level; then applied the correction again to the first differences of resulting series ($\Delta r_{i,t}$). Extreme observations were similarly omitted in all firm-level variables.

costs, which are available in CADS[21]; firm averages are then taken across the whole period. Note that all results presented in this paper are fairly robust to the use of alternative definitions of this ratio (e. g. using total sales as the denominator). The mean h (across firms and time) is equal to 0.33, i. e. firms keep four months of annual costs in the form of inventories.[22] Luckily for our research strategy, h_i displays a large cross-sectional variability, ranging from slightly below zero to 1.09 (Figure 3), thus effectively discriminating between firms with different working capital requirements.

As for the remaining variables, the variable $(1-\gamma_i)\dot{w}_{s,t}$ is constructed by multiplying two-digit sectoral changes in contractual wages (ISTAT) by $(1-\gamma_i)$, with γ_i set equal to the firm-specific average ratio between input and service costs and total costs (CADS) (the sample mean of γ is around 0.76); similarly, the variable $\gamma_i \dot{v}_{s,t}$ is constructed by multiplying two-digit sectoral log-changes in input prices (ISTAT) by γ_i. The variable ($(1-\gamma_i)U\dot{L}C_{i,t}$) is constructed by subtracting the log-change in real sales (SIM) from the nominal log-change in labour costs (CADS) and multiplying it by $(1-\gamma_i)$; similarly, the variable $\gamma_i\, U\dot{M}C_{i,t}$ is constructed by subtracting the log-change in real sales (source: SIM) from the log-change in material costs (CADS) and multiplying it by γ_i. The variable ($\dot{y}_{i,t} - \gamma_i \dot{M}_{i,t} - (1-\gamma_i)\dot{N}_{i,t}$) is constructed by subtracting from the log-change in real sales (source: SIM) the log-change in material input at constant prices (nominal total input cost deflated with sectoral input prices) and the log-change of labour input (change in average number of employees, source: CADS), appropriately weighted. Finally, the firm-level rate of capacity utilization ($CU_{i,t}$) is available in SIM as the answer to a specific question ("what is the ratio between actual production and the level of production which would be possible fully using the available capital goods without changing labour inputs?"). The correlation between the annual across-firm mean of this variable and a standard macro-measure of

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[21] In CADS, operating costs are defined as the sum of purchases of materials, intermediate and services, labour costs, interest expenses and depreciation allowances. In all cases when data on commercial credit and debit were missing, the ratio was computed as the inventory/operating costs ratio (the estimates were not significantly affected).

[22] The average ratio to total sales is only marginally smaller and equal to 0.32.

capacity utilization in manufacturing (computed by the Bank of Italy based on industrial production and quarterly surveys by ISAE) is equal to 0.78.

5. A panel estimation of the cost channel

The fixed-effect estimates of equation (6) and (7) are shown respectively in Tables 6 and 7, where our three measures of interest rate changes ($\Delta r^{CR}_{i,t}$, $\Delta r^{CA}_{i,t}$, Δr^{P}_{t}) are used alternatively as a regressor and time dummies are included. Time dummies control for all aggregate effects, including movements in demand, cyclical behaviour of margins and, most notably for our purposes, traditional effects of monetary policy.[23] As a consequence, the estimates of a_4-a_5 in equation (6) and b_3–b_4 in equation (7) only capture firm-specific effects and can be interpreted as directly measuring the cost effect of interest rate changes. If firms incur costs in financing working capital, the coefficient on the first interaction term (alternatively $h_i\Delta r^{CR}_{i,t}$, $h_i\Delta r^{CA}_{i,t}$ $h_i\Delta r^{P}_{t}$) should be positive and equal to one. If, in addition, firms have to anticipate labour costs, the coefficient on the second interaction term (alternatively $(1-\gamma_i)\Delta r^{CR}_{i,t}$, $(1-\gamma_i)\Delta r^{CA}_{i,t}$, $(1-\gamma_i)\Delta r^{P}_{t}$) should be positive and equal to the (assumed common) proportion of labour costs that are anticipated.

The results in Table 6 show that interest rate changes, when interacted with the working capital ratio, affect the firm's price with a positive and highly significant coefficient, although its magnitude varies across the estimated regressions. In contrast, the coefficient on the second interaction term is usually not significantly different from zero (with one exception), indicating that the entire cost channel effect is explained by the amount of working capital held by the firm, while the assumption that all firms have to finance the advance payment of labour costs in the same proportion is not unambiguously supported by the data.

When the changes in the bank rate on short-term bank lending applied to each firm, measured at the beginning of the period, are used to construct the regressor ($h_i\Delta r^{CR}_{i,t-1}$, first and second columns), the corresponding coefficient is positive and statistically significant,

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[23] The model was estimated alternatively with time dummies interacted with sector dummies, with no major difference in the results.

although smaller than the unit value implied by equation (4). It is also positive and highly significant when the implicit average interest rate on a firm's debt is used ($h_i \Delta r^{CA}_{i,t}$, third and fourth second columns), although even smaller in absolute value. The coefficient is larger than in the previous cases and not significantly different from 1, when the lagged change in the policy rate ($h_i \Delta r^{P}_{t-1}$, fifth and sixth columns) is used to construct the regressors[24].

In contrast, the estimates corresponding to coefficient a_4 are not statistically significant in two cases out of three (namely, when firm-specific measures of interest rates, $(1-\gamma_i)\Delta r^{CR}_{i,t}$ and $(1-\gamma_i)\Delta r^{CA}_{i,t}$, are used); the estimate is positive and significant only when aggregate interest rates ($(1-\gamma_i) r^{P}_{t-1}$) are used. This evidence suggests that either firms do not incur costs in anticipating wages or that the share of labour costs that have to be anticipated is not common across firms, as implied in deriving our equations. When this variable is omitted from the regression, the other estimates are not affected (this is done in columns 2, 4 and 6 of Table 6).

The estimates of the remaining coefficients are to a large extent consistent with what was expected on the basis of equation (4). Price changes respond one-to-one (or more) to a change in input prices (the coefficient on $\gamma_i \Delta v_{s,t}$ is always very close to 1), almost one-to-one to a change in wages (the coefficient on $(1-\gamma_i)\Delta w_{s,t}$ is positive and highly significant, but somewhat smaller than one)[25] and positively to capacity utilization (the coefficient on $CU_{i,t}$ indicates that an increase in capacity utilization by 10 per cent reduces the price of the firm's output by about 60 basis points). Only the link to productivity is negative and highly significant, but quite small in absolute value.[26]

Table 7 shows the results from a corresponding battery of regressions based on equation (7), which uses firm-specific data on unit costs rather than sectoral wages and input prices. The estimates of the coefficient b_3 are remarkably robust across regressions and of

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[24] Lagged levels of the policy rate are included, on the grounds that it is likely to affect the average rate on firms' debt with a lag. In this case, of course, cross-sectional variability in $h_i \Delta r^{P}_{t-1}$ only depends on h_i

[25] Both findings resemble those obtained by Bils and Chang (2000) on US three-digit sectoral data.

[26] The coefficient is smaller in absolute value than the one estimated by Marchetti and Nucci (2002) for various productivity measures (their estimated coefficients are somewhere around -0.3). Bils and Chang (2000) also find that the impact of changes in TFP on the change in prices (our coefficient a_4) is less than one. For our purposes, the omission of this variable does not affect the estimates of the other coefficients.

the same order of magnitude as those in Table 6. The coefficients on the firm-level interest rates, when interacted with working capital, are still statistically different from zero and smaller than one (the point estimate is between 0.4 and 0.6), while the coefficients on the policy rate are also highly significant but not statistically different from 1. As before, the estimates of the coefficient b_4 are inconclusive (negative in one case, positive in a second case, not significantly different from zero in a third case). Capacity utilization still enters the price equation with the expected positive sign. The coefficients on the cost variables, unit labour cost ($(1-\gamma_i)\Delta ULC_{i,t}$) and unit material cost ($\gamma_i \Delta UMC_{i,t}$) are still positive and significant, although now much smaller than 1. The estimates of these coefficients may be downward biased due to measurement errors in the dependent variables *ULC*, *UMC*, when obtained from balance-sheet data. For our purposes, it is relevant that the estimates of the cost channel effect are robust to the change in the specification.

All in all, our estimates of the cost channel effect are consistent with the model presented in Section 3, although the magnitude of the estimates is somewhat smaller than expected. A possible explanation is the relatively restrictive hypothesis adopted to go from equation (3) to equations (4) and (5), namely that firms instantaneously adjust prices to movements in marginal costs. In contrast with this assumption, a large theoretical and empirical literature argues that sticky price adjustment is an essential feature of market economies and that intervals between price revisions may sometimes be fairly large. In this environment firms do not set prices simply looking at current marginal cost, but at the discounted stream of expected future marginal cost[27]. In this case, the impact on prices of *current* marginal costs would be smaller than one, *ceteris paribus*; the same would hold for most explanatory variables on the right-hand side of equations (6) and (7), unless they also affect future expected marginal costs.

Finding out whether this is the case is important, firstly, to assess whether smaller than expected estimates of the cost channel effect, as in Table 6, signal a failure of the model presented in Section 3, or can rather be explained just by relaxing the assumption of instantaneous price adjustment. To this end we exploit firm-level information on the frequency of price adjustment available in SIM. This information stems from a specific question that was introduced in the 1996 survey. In that year the respondents were asked to choose from five possible responses to the question "how frequently does your firm typically modify selling prices?". [28] The survey results point to more frequent price adjustments than found in other international studies; in our sample, about 70 per cent of respondents declare they revise prices at least every six months, and a third of them at least every three months.[29]

To verify whether the estimated size of some parameters is closer to that suggested by the theoretical model when the estimation is restricted to firms which adjust their prices often, we split the sample into two groups of firms. We interact all coefficients with a dummy variable *D*, taking value 0 for the firms that change prices at a frequency equal to or greater than three months, 1 otherwise. The results are reported in Table 8. As expected, the adjustment of prices to most right-hand side variables is substantially smaller for the firms that adjust prices infrequently (the coefficients on variables interacted with *D* are mostly negative). This is not surprising and is even to a large extent obvious. What is more interesting for our purposes is that the estimated coefficients for the frequently adjusting firms (those for which $D=0$) now match the theoretical model much more closely. In particular, unlike the estimates in the previous section, the point estimate of the coefficient on the change of firm-level interest rates interacted with working capital is now quite close to one; the assumption that it is equal to one can be rejected only in one case. This evidence reinforces the conclusion that an effect on marginal costs is at work, whose size is entirely consistent with the implications of equation (4).

6. Is the cost channel effect economically relevant?

Is the cost channel effect which we estimated economically - in addition to statistically - relevant? We can summarize our quantitative results as follows.

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[27] This is the case under the assumption of price adjustment *à la* Calvo.

[28] The admissible answers were: several times a month; every month; every 3 months; every 6 months;, once a year or less frequently.

[29] Information on the frequency of actual price changes would be preferable as a measure of price stickiness. However, Blinder et al. (1996) and Hall et al. (2000) document a strong positive correlation between the frequency of price revisions and the frequency of price changes. In the case of the SIM survey, the Bank of Italy interviewers reported that the re-examination of prices often coincided with their actual change;

Firstly, our estimates suggest that over the whole sample the coefficient on the interaction variables $h_i \Delta r^{CA}_{i,t}$, $h_i \Delta r^{CR}_{i,t}$ $h_i \Delta r^{P}_{t}$ in the price equation is between 0.3 and 1. Secondly, in our sample, h_i, the mean ratio of working capital to annual operating costs is around 0.33. On average, then, firms hold four months worth of operating costs as working capital, which has to be financed. As a consequence, a one per cent rise in (annualized) interest rates may induce an increase in prices between 10 and 30 basis points. Such an effect on prices, while not extraordinarily large, is not negligible. As a benchmark, in Italy during the three main monetary restrictions in the period 1988 - 1998, the overall average policy rate increase was between 3 and 5.5 percentage points. These figures would imply an overall adverse effect on prices ranging from 0.3 to 1.6 percentage points, which would have partly counterbalanced the disinflationary effect operating through the demand side. While hardly enough to change the overall effect of monetary policy on prices over the medium run, this impact may not be without relevance.

Is this effect enough to alter the optimal course that monetary policy should follow in response to various disturbances? A full answer goes beyond the scope of this paper, since it needs to be addressed in a general equilibrium framework. However, a tentative assessment can be offered by considering the implications of the model of Ravenna and Walsh (2003). That model incorporates the assumption that production costs have to be anticipated by one quarter, or, equivalently, that working capital is equal to one fourth of annual costs and that its financing is entirely transferred onto marginal costs. That assumption bears a close resemblance to the features of our sample: the average period over which costs have to be anticipated as working capital is slightly above one quarter, while the regressions in Table 8 show that the corresponding interest cost is fully reflected in marginal costs. In the Ravenna and Walsh model, under this assumption, and for a standard calibration of the remaining parameters, the appropriate policy response to shocks turns out to be affected; the cost channel calls for a more gradual response to shocks than would otherwise happen (an illustration is in Appendix I).

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furthermore, Fabiani et al. (2003) conduct a survey on a different sample of Italian firms and confirm the close relationship between the frequency of price reviews and that of actual price changes.

7. Conclusions

We draw three implications from our study.

Methodologically, using a unique dataset, we conclude that individual data on firms' pricing behaviour give robust and direct evidence of the fact that monetary policy also works through the supply side; unlike previous results, we consider this evidence to be largely immune to the identification problem which plagues the time-series literature. By observing individual firms' pricing behaviour we are also able to obtain a more reliable estimate of the magnitude of the cost channel effect.

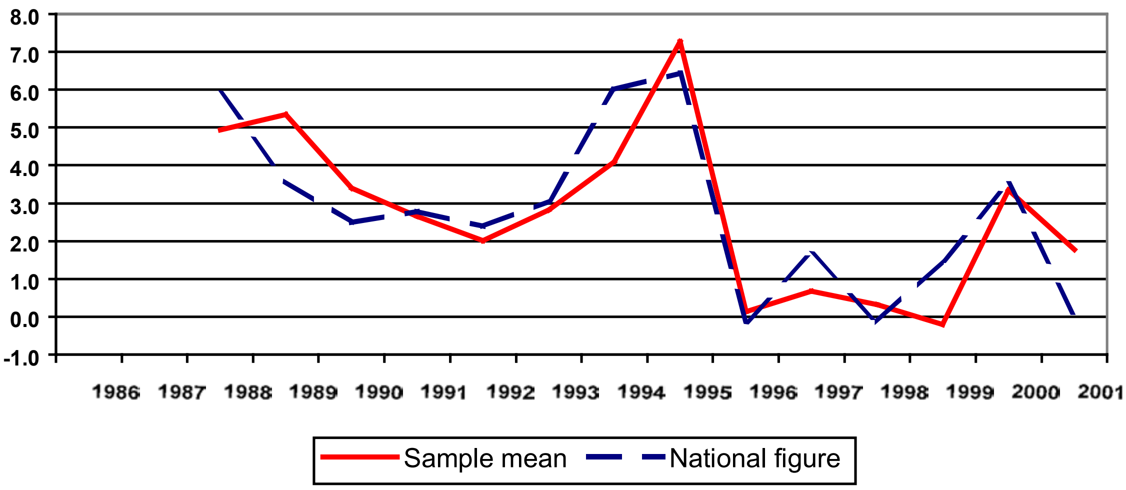
Economically, we find the effect of interest rates on prices to be proportional to the ratio between working capital and sales, thus supporting the view that the cost channel effect is intrinsically linked to the role of working capital in the production process of the firm, that is, in the end, to a mismatch between payments and receipts. This result is quite robust to alternative measures of firm-level interest rates from different sources. In contrast, we find little evidence of a separate interest rate effect related to the anticipation of wage payments, which is the assumption commonly adopted in the theoretical literature, in addition to that already captured by the measure of working capital.

From a normative point of view, the effect is economically significant; the adverse impact of interest rate hikes on the price level during a typical restriction cycle may not be negligible; the magnitude of the supply-side effect is such that it affects the optimal course of policy, possibly calling for more gradualism.

Tables and figures

Figure 1 - Output prices

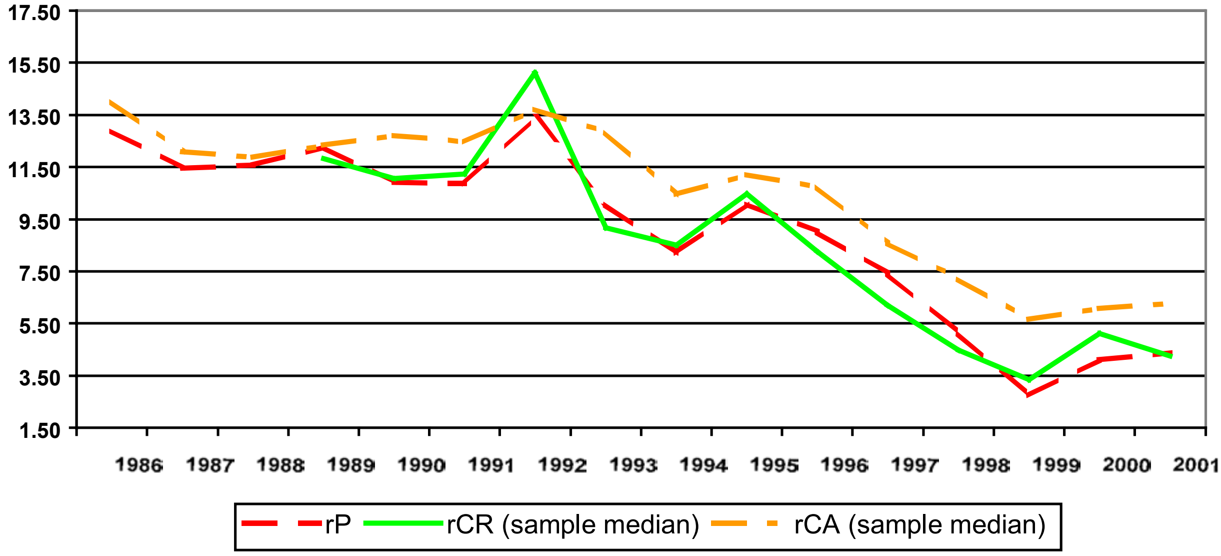
(annual percentage change)



Sample mean: sample mean of the change in the price of output (source: SIM). National figure: annual percentage change in output prices, excluding food and energy (Source: Istat).

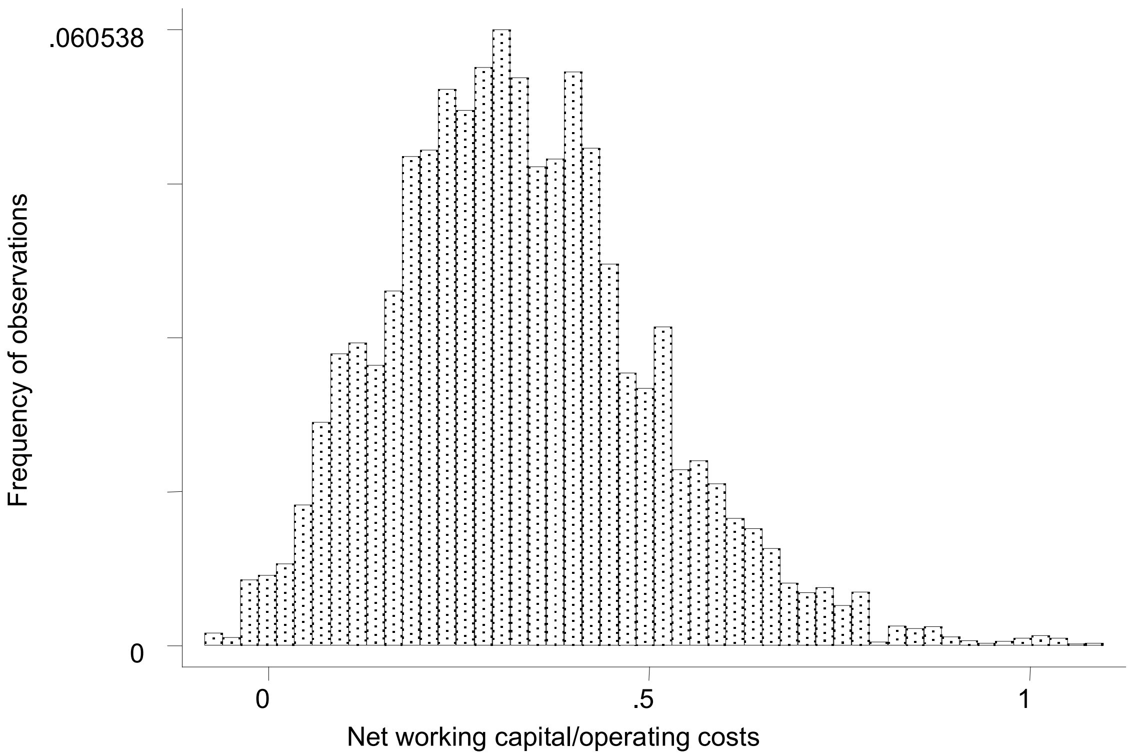
Figure 2 - Interest rates

(percentage points)



Definition of the variables and sources: see text.

Figure 3 - Frequency distribution of the net working capital/operating costs ratio



Source: CADS

Table 1: Number of observations per year

Year	1988	1989	1990	1991	1992	1993	1994
Observations	521	542	541	577	596	594	626

Year	1995	1996	1997	1998	1999	2000	2001
Observations	663	748	723	766	781	1,024	1,049

Table 2 - Total sample composition according to geographical position

	North-west	North-east	Centre	South and Isl.	Total
Observations	4086	2467	1783	1415	9751
Frequency	*41.9*	*25.3*	*18.29*	*14.51*	
Population in 1995 (1)	*44.45*	*30.38*	*14.88*	*10.28*	

Numbers in Roman type denote the number of firms belonging to each of the four macro regions, those in italics the relative frequency of the different groups. The source for the distribution of the population of firms is ISTAT. (1) In 1995 the number of firms in manufacturing with more than 50 employees was equal to 10881. In 1996 the total number of manufacturing firms was 551,000, those with more than 50 employees numbered 11,453, the annual average number of firms in our sample is equal to 697.

Table 3 - Total sample composition according to size

Year	50 – 99	100 - 199	200 – 499	500 – 999	1000 +	Total
Observations	2336	2511	2736	1212	956	9751
Frequency	*23.96*	*25.75*	*28.06*	*12.43*	*9.8*	*100*
Population in 1995 (1)	*55.57*	*26.25*	*13.23*	*3.04*	*1.90*	

Numbers in Roman type denote the number of firms belonging to each of the five size groups; those in italics the relative frequency of the different classes. The source for the distribution of the population of firms is ISTAT.

Table 4 - Total sample composition according to sector

Year	Textile, clothing, leather and footwear	Chemicals, rubber and plastic	Metals and machinery	Manufacturing: others	Total
Observations	1979	1233	3743	2796	9751
Frequency	*20.3*	*12.64*	*38.39*	*28.67*	*100*
Population in 1995 (1))	*21.04*	*10.75*	*41.83*	*26.38*	

(1) In 1995 the number of firms in manufacturing with more than 50 employees was equal to 10,881, the annual average number of firms in our sample is equal to 697. The four sectors reported in Table 4 have been obtained by aggregating two-digit ATECO91 subsectors. “Textile, clothing, leather and footwear” corresponds to subsectors DB and DC, “Chemicals, rubber and plastic” to subsectors DF, DG and DH, “Metals and machinery” to subsectors DJ, DK, DL and DM, “Manufacturing: others” to all the remaining manufacturing sectors. Numbers in Roman type normal case denote the number of firms belonging to each of the four macro sectors; those in italic the relative frequency of the different groups. The source for the distribution of the population of firms is ISTAT. In 1995 the number of firms in manufacturing with more than 50 employees was equal to 10881, the annual average number of firms in our sample is equal to 697.

Table 5 - Basic statistics on main variables

	N	Mean	Std.Dev.	5%	10%	25%	50%	75%	90%	95%
$\Delta P_{i,t}$	9751	2.55	6.25	-6.00	-3.00	0.00	2.50	5.00	8.00	10.00
$\Delta r^{CR}_{i,t-1}$	3741	-0.65	2.49	-5.60	-3.46	-1.96	-0.84	1.09	2.34	3.79
$\Delta r^{CA}_{i,t}$	6062	-0.39	3.16	-6.14	-4.55	-2.25	-0.22	1.55	3.51	4.89
$\Delta r^{P}_{i,t}$	9751	-0.66	1.71	-3.35	-2.39	-1.86	-1.37	0.70	1.88	2.56
h_i	9719	0.33	0.17	0.08	0.12	0.21	0.32	0.43	0.56	0.64
$\Delta w_{s,t}$	9751	3.82	2.42	1.33	1.71	2.04	3.10	5.53	6.06	10.41
$\Delta v_{s,t}$	9751	3.10	3.76	-1.78	-0.71	0.82	3.07	4.85	6.92	8.34
$\Delta ULC_{i,t}$	7934	3.00	30.59	-19.23	-13.29	-5.73	1.21	9.20	18.79	26.67
$\Delta UMC_{i,t}$	7933	5.51	72.62	-22.46	-15.54	-5.87	2.85	12.26	24.30	34.43
$\Delta prod_{i,t}$	7775	2.88	14.44	-17.56	-10.79	-3.93	2.32	9.09	17.54	24.49
$CU_{i,t}$	9670	80.72	12.52	60.00	65.00	75.00	81.00	90.00	95.00	98.00
γ_i	9751	0.76	0.11	0.55	0.61	0.70	0.77	0.84	0.89	0.91

Source: SIM, CADS, CR.

Table 6 – The price equation I

$(1-\gamma_i)\Delta w_{s,t}$	0.802** 0.287	0.801** 0.286	0.664** 0.215	0.667** 0.215	0.628** 0.179	0.623** 0.179
$(\gamma_i)\Delta v_{s,t}$	1.351** 0.060	1.351** 0.060	0.957** 0.045	0.956** 0.045	0.929** 0.040	0.930** 0.040
$\Delta prod_{i,t}$	-0.090** 0.008	-0.090** 0.008	-0.080** 0.006	-0.080** 0.006	-0.074** 0.005	-0.074** 0.005
$h_i\Delta r^{CR}_{i,t-1}$	0.478** 0.242	0.529** 0.198				
$(1-\gamma_i)\ \Delta r^{CR}_{i,t-1}$	0.127 0.350					
$h_i\Delta r^{CA}_{i,}$			0.383** 0.137	0.233** 0.065		
$(1-\gamma_i)\ \Delta r^{CA}_{i}$			-0.240 0.193			
$h_i\Delta r^{P}_{t-1}$					0.682** 0.240	0.939** 0.232
$(1-\gamma_i)\Delta r^{P}_{t-1}$					1.470** 0.363	
$CU_{i,t}$	0.054** 0.013	0.054** 0.013	0.057** 0.009	0.057** 0.009	0.061** 0.008	0.060** 0.008
R^2	0.31	0.31	0.24	0.24	0.24	0.23
Observations	3654	3654	5940	5940	7709	7709
Firms	904	904	1443	1443	1652	1652

Fixed effects estimation. Time effects included. The variables are those defined in equation (6) in the main text. A subscript "*i*" stands for the firm, a subscript "*s*" stands for the (two-digit) industry, and a subscript "t" stands for the time period. A (**) denotes a parameter that is significant at a 5 per cent confidence level, a (*) a parameter that is significant at a 10 per cent confidence level.

Table 7 - The price equation II

$(1-\gamma_i)\Delta ULC_{i,t}$	0.138^{**} 0.031	0.138^{**} 0.031	0.178^{**} 0.022	0.181^{**} 0.022	0.158^{**} 0.018	0.160^{**} 0.018
$(\gamma_i)\Delta UMC_{i,t}$	0.210^{**} 0.009	0.210^{**} 0.009	0.183^{**} 0.006	0.183^{**} 0.006	0.167^{**} 0.005	0.168^{**} 0.005
$h_i\Delta r^{CR}_{i,t-1}$	0.580^{**} 0.238	0.565^{**} 0.194				
$(1-\gamma_i)\Delta r^{CR}_{i,t-1}$	-0.037 0.341					
$h_i\Delta r^{CA}_{i,t}$			0.581^{**} 0.133	0.365^{**} 0.063		
$(1-\gamma_i)\Delta r^{CA}_{i,t}$			-0.346^{*} 0.186			
$h_i\Delta r^{P}_{t-1}$					0.781^{**} 0.231	0.942^{**} 0.223
$(1-\gamma_i)\Delta r^{p}_{t-1}$					0.914^{**} 0.357	
$CU_{i,t}$	0.038^{**} 0.013	0.038^{**} 0.013	0.050^{**} 0.009	0.051^{**} 0.009	0.050^{**} 0.008	0.050^{**} 0.008
R^2	0.31	0.31	0.28	0.28	0.27	0.27
Observations	3686	3686	5939	5939	7725	7725
Firms	909	909	1445	1445	1651	1651

Fixed effects estimation. Time effects included. The variables are those defined in equation (7) in the main text. A subscript "*i*" stands for the firm, a subscript "*s*" stands for the (two-digit) industry, and a subscript "t" stands for the time period. A (**) denotes a parameter that is significant at a 5 per cent confidence level, a (*) a parameter that is significant at a 10 per cent confidence level.

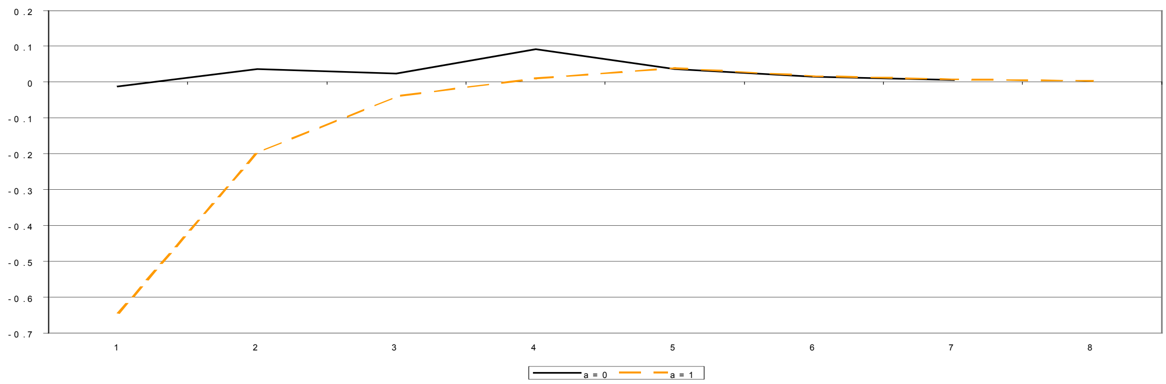
Table 8 – The price equation and the frequency of price adjustment

$(1-\gamma_i)\Delta w_{s,t}$	0.761	1.288**	1.135**	$(1-\gamma_i)\Delta ULC_{i,t}$	0.299**	0.327**	0.263**
	0.546	0.459	0.393		0.061	0.047	0.041
$D*(1-\gamma_i)\Delta w_{s,t}$	-0.019	-1.128**	-0.763	$D*(1-\gamma_i)\Delta ULC_{i,t}$	-0.225**	-0.197**	-0.113**
	0.670	0.553	0.468		0.072	0.055	0.048
$(\gamma_i)\Delta v_{s,t}$	1.676**	1.035**	1.021**	$(\gamma_i)\Delta UMC_{i,t}$	0.325**	0.324**	0.297**
	0.090	0.067	0.061		0.014	0.011	0.010
$D*(\gamma_i)\Delta v_{s,t}$	-0.952**	-0.474**	-0.446**	$D*(\gamma_i)\Delta UMC_{i,t}$	-0.215**	-0.225**	-0.197**
	0.128	0.098	0.087		0.018	0.015	0.013
$h_i\Delta r^{CR}_{i,t-1}$	0.891**			$h_i\Delta r^{CR}_{i,t-1}$	0.814**		
	0.351				0.336		
$D*h_i\Delta r^{CR}_{i,t-1}$	-0.533			$D*h_i\Delta r^{CR}_{i,t-1}$	-0.412		
	0.435				0.415		
$h_i\Delta r^{CA}_{i,t}$		0.722**		$h_i\Delta r^{CA}_{i,t}$		0.967**	
		0.144				0.133	
$D*h_i\Delta r^{CA}_{i,t}$		-0.656**		$D*h_i\Delta r^{CA}_{i,t}$		-0.821**	
		0.167				0.155	
$h_i\Delta r^{P}_{i,t-1}$			2.120**	$h_i\Delta r^{P}_{i,t-1}$			1.499**
			0.467				0.433
$D*h_i\Delta r^{P}_{i,t-1}$			-1.383**	$D*h_i\Delta r^{P}_{i,t-1}$			-0.732
			0.563				0.524
$CU_{i,t}$	0.122**	0.083**	0.098**	$CU_{i,t}$	0.084**	0.071**	0.090**
	0.025	0.019	0.017		0.024	0.017	0.016
$D*CU_{i,t}$	-0.093**	-0.050**	-0.062**	$D*CU_{i,t}$	-0.063**	-0.039*	-0.056**
	0.030	0.023	0.020		0.028	0.021	0.019
$\Delta prod_{i,t}$	-0.158**	-0.125**	-0.117**				
	0.015	0.010	0.009				
$D*\Delta prod_{i,t}$	0.109**	0.071**	0.066**				
	0.018	0.014	0.011				
R^2	0.37	0.30	0.29	R^2	0.41	0.39	0.36
Observations	2988	4215	5425	Observations	3012	4215	5449
Firms	583	702	755	Firms	584	703	755

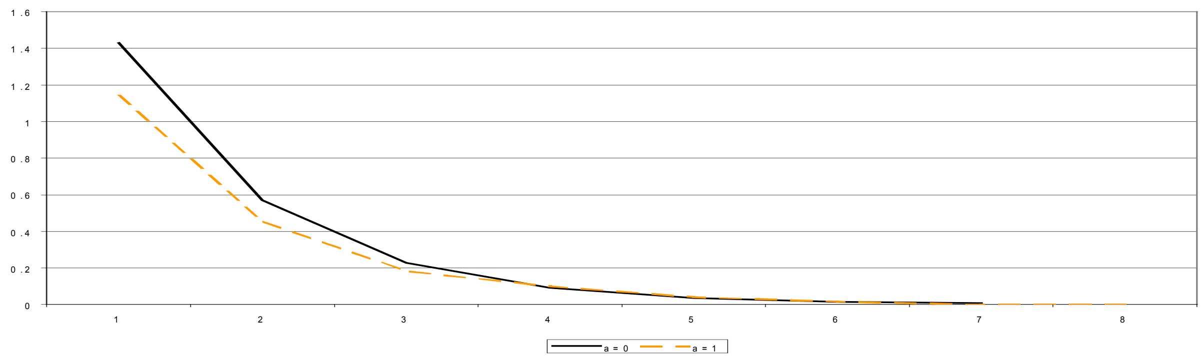
Fixed effects estimation. Time effects included. The variables are those defined in equations (6) and (7) in the main text. A subscript "i" stands for the firm, a subscript "s" stands for the (two-digit) industry, and a subscript "t" stands for the time period. Only firms that declared they usually adjust prices every three months or less are included. A (**) denotes a parameter that is significant at a 5 per cent confidence level, a (*) a parameter that is significant at a 10 per cent confidence level. The dummy variable *D* is equal to 1 for those firms whose frequency of review is equal to or less than 3 months, equal to 0 otherwise. The *D* dummy has been also interacted with time effects.

Figure A - Optimal interest rate responses

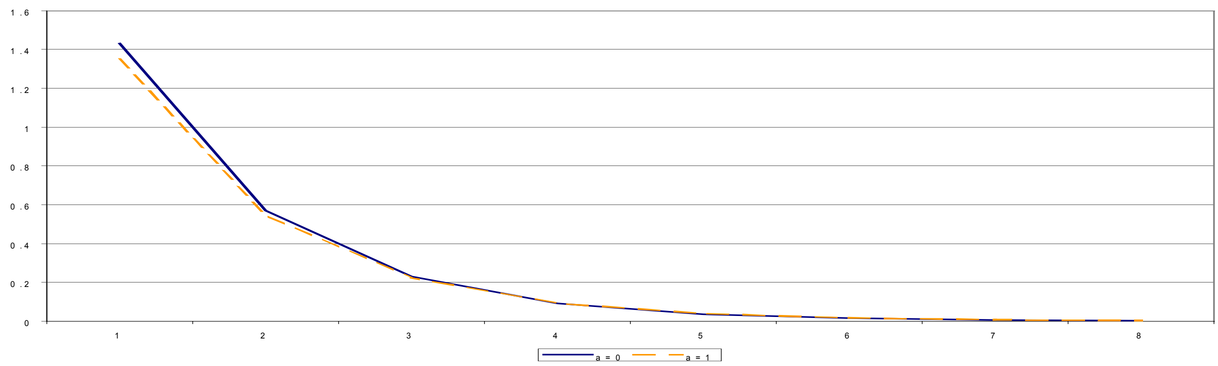
Cost-push shock under commitment



Cost-push shock under discretion



Demand shock under commitment



Optimal response of the interest rate to a unit cost-push shock or to a demand shock (see the model in Appendix I). Dotted line (a=1): cost channel effect. Continuous line (a=0): no cost channel effect.

Appendix I

In this Appendix, some policy implications of (a linearized version of) the model by Ravenna and Walsh (2003) are presented in order to illustrate how, in a sticky-price, general equilibrium framework, the existence of a cost channel can alter the optimal course of monetary policy in the face of various shocks.

(8) $$\pi_t = \beta\pi_{t+1|t} + k \ mc_t + \omega_t$$

(9) $$x_t = x_{t+1|t} - \sigma^{-1}(r_t - \pi_{t+1|t}) + \varepsilon_t$$

(10) $$mc_t = w_t - p_t + ar_t^Q$$

(11) $$w_t - p_t = (\sigma + \varphi)x_t$$

(12) $$\omega_t = \rho_\omega \omega_{t-1} + o_t$$

(13) $$\varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \upsilon_t$$

(14) $$L_t = (\pi_t^2 + \lambda x_t^2)$$

where time t is measured in quarters, π_t, mc_t, x_t, r^Q_t , w_t - p_t are (quarter-on-quarter) inflation, the log-marginal cost of production, the log-output gap[30], the quarterly nominal interest rate and the real wage (all variables in deviation from steady state), ω_t, ε_t are respectively a cost-push and a demand shock, with an autoregressive structure, and L_t is the period loss function. We calibrate the model broadly following Ravenna and Walsh (2003): β=0.99, φ=*1*, k=0.085, σ=1.5, λ=0.25. For the sake of simplicity, we introduce the shocks ω_t, ε_t *ad hoc*, rather than derive them from micro-foundations, and label them "cost-push" and "demand". We impose ρ_ω=ρ_ε=0.4.

The coefficient *a* measures the effect of the interest rate on marginal costs. Ravenna and Walsh set it equal to 1, based on the microeconomic assumption that all wages are paid one quarter in advance. Note that equation (11) can also be written in terms of the *annualized* interest rate (r_t^A=4 r_t^Q), in which case the corresponding coefficient on this variable would be *a/4 =0.25* (this formulation is more directly comparable with our results in the main text).

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[30] The output gap is defined as the deviation of output from its flexible price level. See Ravenna and Walsh (2003) for a precise definition in this setting.

The central bank minimizes $\sum_{i=0}^{\infty} \beta^i L_{t+i}$. The optimal response of monetary policy to a unit innovation o_t (cost-push) or υ_t (demand) can be derived, as a function of the parameter *a*, both under commitment and under discretion, applying the procedure and the Matlab codes suggested by Gerali and Lippi (2003).

The first panel in Figure A shows that, in the case of a cost-push shock, when *a=0* the optimal policy under commitment consists in increasing interest rates moderately and gradually over time (continuous line)[31]; the central bank faces the usual trade-off between contrasting the increase in inflation and offsetting the fall in output. In sharp contrast, when the interest rate is allowed to affect marginal costs (*a=1*), the optimal policy turns out to be an interest rate easing, even in the face of rising inflation (dotted lines). The intuition is simple: the central bank can in part offset the adverse cost-push shock by decreasing rates, thus relieving firms of interest expenses on their working capital. However, its ability to do so is limited by the adverse demand effect on prices, induced by an interest rate decrease. Under a fully discretionary policy (Figure A, second panel), even when *a=1*, the central bank has to increase interest rates rapidly to offset the effect of the cost-push shock on prices, as it cannot take advantage of the effect of its future behaviour on inflation expectations. However, the increase is smaller when the cost channel is present.

The optimal policy reaction after an expansionary demand shock is less affected by the cost channel (Figure A, third panel). When *a=0*, policy is tightened in order to offset exactly the shock (disinflation is a free lunch). When *a=1,* the monetary restriction must be somehow milder because of its simultaneous adverse effects on supply. Since monetary policy has both supply and demand effects, it cannot exactly offset the consequences of a demand shock on prices without a cost in terms of output. However, the size of this effect is limited, at least for this calibration of the model.

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[31] The small size and persistence of the interest rate increase is a standard consequence of the central bank's ability to commit, keeping expectations of future inflation under control.

Appendix II

We define:

(15)
$$v_t' = v_t(1 + k_M r_t)$$
$$w_t' = w_t(1 + k_N r_t)$$

and, taking log changes (indicated by a dot on the top of a variable):

(16)
$$\dot{v}_t' = \dot{v}_t + \Delta\log(1 + k_M r_t) \cong \dot{v}_t + k_M \Delta r_t$$
$$\dot{w}_t' = \dot{w}_t + \Delta\log(1 + k_N r_t) \cong \dot{w}_t + k_N \Delta r_t$$

We rewrite total cost as:

(17)
$$C_t = v'_t M_t + w'_t N_t + c_t K_t$$

The first order conditions of the cost minimization problem of the firm imply:

(18)
$$N_t = \left(A^{-1} y_t\right)^{\frac{1}{\delta+\alpha+\beta}} \left[\left(\frac{\beta c_t}{\alpha w_t'} \right)^{\alpha} \left(\frac{\beta v_t'}{\delta w_t'} \right)^{\delta} \right]^{\frac{1}{\delta+\alpha+\beta}}$$

(19)
$$K_t = \left(\frac{\alpha w_t'}{\beta c_t} \right) N_t$$

(20)
$$M_t = \left(\frac{\delta w_t'}{\beta v_t'} \right) N_t$$

From (19) we get:

(21)
$$\dot{N}_t + \dot{w}_t' = \dot{K}_t + \dot{c}_t$$

Total cost is given by :

$$C_t = v_t' M_t + w_t' N_t + c_t K_t = \left[\frac{\alpha+\beta+\delta}{\beta}\right] w_t' N_t =$$

(22)
$$= \left[\frac{\alpha+\beta+\delta}{\beta}\right] w_t' \left[\left(\frac{\beta c_t}{\alpha w_t'}\right)^{\alpha}\left(\frac{\beta v_t'}{\delta w_t'}\right)^{\delta}\right]^{\frac{1}{\delta+\alpha+\beta}} \left(A_t^{-1} y_t\right)^{\frac{1}{\delta+\alpha+\beta}}$$

$$= (\alpha+\beta+\delta)\left[\left(\frac{c_t}{\alpha}\right)^{\alpha}\left(\frac{w_t'}{\beta}\right)^{\beta}\left(\frac{v_t'}{\delta}\right)^{\delta}\right]^{\frac{1}{\delta+\alpha+\beta}} \left(A_t^{-1} y_t\right)^{\frac{1}{\delta+\alpha+\beta}}$$

The marginal cost and the log-change in the marginal cost are then given by:

(23)
$$MC_t = \frac{\partial C_t}{\partial y_t} = \left[\left(\frac{c_t}{\alpha}\right)^{\alpha}\left(\frac{v_t'}{\delta}\right)^{\delta}\left(\frac{w_t'}{\beta}\right)^{\beta}\right]^{\frac{1}{\delta+\alpha+\beta}} A_t^{\left(-\frac{1}{\delta+\alpha+\beta}\right)} y_t^{\left(\frac{1}{\delta+\alpha+\beta}-1\right)}$$

(24)
$$\dot{MC}_t = \frac{\beta}{\delta+\alpha+\beta}\dot{w}_t' + \frac{\alpha}{\delta+\alpha+\beta}\dot{c}_t + \frac{\delta}{\delta+\alpha+\beta}\dot{v}_t' + \left(\frac{1}{\delta+\alpha+\beta} - 1\right)\dot{y}_t - \frac{1}{\delta+\alpha+\beta}\dot{A}_t$$

Considering (21), this equation can be more conveniently written as:

(25)
$$\dot{MC}_t = \frac{\beta+\alpha}{\delta+\alpha+\beta}\dot{w}_t' + \frac{\delta}{\delta+\alpha+\beta}\dot{v}_t' + \left(\frac{1}{\delta+\alpha+\beta}\left(\dot{y}_t - \dot{A}_t\right) - \dot{y}_t\right) + \frac{\alpha}{\delta+\alpha+\beta}\left(\dot{N}_t - \dot{K}_t\right)$$

Considering that $\dot{y}_t = \dot{A}_t + \delta\dot{M}_t + \beta\dot{N}_t + \alpha\dot{K}_t$ and based on (16), we obtain (3) in the text.

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