Inflation, Output, and Markup Dynamics with Forward-Looking Wage and Price Setters

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Abstract

We formulate a medium-scale DSGE model that emphasizes a strong interplay between firms networking and a working capital channel that requires firms to borrow funds to finance the costs of all their variable inputs and not just the wage bill. Despite an absence of backward-looking price and wage indexation, our model is able to account for (i) a persistent and hump-shaped response of inflation to a monetary policy shock, (ii) a large and persistent response of output to a monetary policy shock, (iii) a mild “price puzzle,” (iv) a procyclical price markup conditional on a monetary shock, (v) a non-inertial response of inflation to a TFP shock, and (vi) a negative unconditional autocorrelation of the first difference of inflation that is consistent with the data. A medium-scale model relying on backward indexation of wages and prices to past inflation fails along several of these dimensions.

JEL classification: E31, E32.

Keywords: New Keynesian Model; Intermediate Inputs; Financial Intermediation; Inflation Dynamics; Price Puzzle; Cyclical Markups.

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1 Introduction

In this paper, we challenge the view that New Keynesian models with purely forward-looking wage and price setting cannot explain inertial inflation and output dynamics in response to a change in aggregate demand (Chari, Kehoe and McGrattan, 2000; Mankiw and Reis, 2002). We also call into question a well-received idea that New Keynesian models must rely on a countercyclical markup of price over marginal cost as a key transmission channel for demand shocks, something that does not seem consistent with the evidence (Galí, Gertler and Lopez-Salido, 2007; Nekarda and Ramey, 2013). We show that a medium-scale DSGE model abstracting from ad hoc backward-looking wage and price setting mechanisms, but emphasizing firms networking and an extended working capital channel allowing firms to finance the costs of intermediate inputs, labor, and capital services can successfully address some of these apparent failures of purely forward-looking New Keynesian models.

To formalize these ideas, we develop a medium-scale DSGE model in the spirit of Christiano, Eichenbaum, and Evans (2005) (hereafter CEE) (see also Smets and Wouters, 2007; Justiniano and Primiceri, 2008; Justiniano, Primiceri and Tambalotti, 2010, 2011). It shares some basic elements of this model like imperfectly competitive goods and labor markets, nominal wage and price rigidities in the form of Calvo (1983) contracts, and real frictions such as consumer habit formation, variable capital utilization, and investment adjustment costs. However, it departs from the CEE model along three important dimensions.

First, our model does not rest on assumptions like the indexation of nominal wages and prices to the previous quarter’s rate of inflation (CEE, 2005) or rule-of-thumb behavior of price setters (Galí and Gertler, 1999). The use of indexation has been criticized by a number of researchers. For instance, Woodford (2007) argues that “the model’s implication that prices should continuously adjust to changes in prices elsewhere in the economy flies in the face of the survey evidence.” Cogley and Sbordone (2008) mention that backward wage and price setting mechanisms “lack a convincing microeconomic foundation.” Chari, Kehoe, and McGrattan (2009) criticize indexation because “this feature is inconsistent with microeconomic evidence on price setting.” In spite of these criticisms, indexation is routinely embedded in medium-scale models as a mechanism by which to generate more inflation inertia.

Second, our model features firms networking (i.e. the use by firms of intermediate goods in an input-output production structure), a characteristic of U.S. production which is well documented empirically with a typical firm selling 50 percent or more of its output to other firms (Basu, 1995;
Huang, Liu, and Phaneuf, 2004).\(^1\) Firms networking is known to introduce strategic complementarities and thereby makes marginal cost less sensitive to input factor prices. As such, it flattens the slope of the New Keynesian Phillips Curve (NKPC). But it has another important implication when used in conjunction with the assumption that firms face a liquidity constraint implying a delay between factor payments and sales receipts. It increases the number of input goods used for production. Therefore, the working capital channel can be extended wherein firms borrow funds from an financial intermediary to finance the costs of more production factors than just labor. As we later show, the interaction between firms networking and an extended working capital channel has an important effect on the response of the price markup to a change in demand, as well as on the dynamics of inflation and output more generally.

Third, as suggested above, in our model the use of working capital is not limited to the wage bill. In the early generation of DSGE models with financial intermediation, firms borrow funds at the beginning of a period from a financial intermediary to finance wages to be paid to workers in the upcoming period (Christiano and Eichenbaum, 1992; Christiano, Eichenbaum and Evans, 1997). Firms then reimburse the loan at the end of the period at some nominal interest rate. There is arguably no theoretical or empirical reason to restrict the use of working capital to labor. For instance, if a typical firm sells 50 percent or more of its output to other firms, the purchases of intermediate inputs will also account for 50 percent or more of input costs. Therefore, working capital can serve to finance the cost of a larger set of inputs, including intermediate inputs. One exception to models in which firms use working capital to finance only wage payments is that of Chowdhury, Hoffmann, and Schabert (2006) in which working capital is used to purchase commodities and finance wage payments. These authors provide VAR evidence for the G7 countries supporting the existence of a significant cost channel consistent with their model specification. Industry-level evidence in Barth and Ramey (2002) also supports the empirical relevance of the cost channel.

In our model, working capital in its extended form is used to finance intermediate inputs, capital services, and labor. We refer to this case as “extended borrowing.” In its limited form, a case we call “limited borrowing”, working capital is used to finance only subsets of these three inputs. We compare two cases with limited borrowing. One is the standard case where working capital serves to finance wage payments only (Christiano, Eichenbaum and Evans, 1992, 1997, 2005; Ravenna and Walsh, 2006; Tillmann, 2008). The other is a case where working capital is used to purchase intermediate inputs only. As we later show, the more inputs which must be financed with working

\(^1\)Christiano (2015) introduces the term “firms networking” to designate a type of model with a roundabout production structure.
capital, the richer are the implications of our purely forward-looking wage and price setting model for the cyclical behavior of markups and the short-run dynamics of inflation and output.

We use our model to address five main questions. A first question is: what are the conditions that our model must satisfy to be able to generate a highly persistent and hump-shaped response of inflation to a monetary policy shock without backward-looking elements in wage and price setting? The second question is: can such a model predict a short-run decline in inflation conditional on an expansionary policy shock known as the “price puzzle”? A third question is: does the model deliver “large” contract multipliers for output in the terminology of Chari et al. (2000)? A fourth question is: can our model generate a procyclical price markup conditioned on a monetary policy shock while predicting a very countercyclical labor wedge – the sum of the logs of wage and price markups – consistent with evidence? Finally, the fifth question is: can we learn something about alternative medium-scale DSGE models by gauging their ability to account for the autocorrelation of the first difference of inflation, which is slightly negative unconditionally in the U.S. data?

Our baseline model predicts a response of inflation which is weakly negative on impact of a negative shock to the nominal interest rate but very persistent and hump-shaped afterwards. The initial fall in inflation following an expansionary monetary policy shock is intriguing given that wage and price setting is purely forward-looking, a point to which we return below. Accompanying our findings regarding the shape of the inflation response, we also show that our model delivers highly serially correlated movements in inflation even at a lag of one year. To the best of our knowledge, our model with purely forward-looking wage and price setting is the first one to generate a strong inertial behavior of inflation consistent with evidence (Fuhrer and Moore, 1995; Nelson, 1998; Pivetta and Reis, 2007).

The key model ingredient which accounts for these findings is the interaction between firms networking and extended borrowing. Without these features, the peak response of inflation to a monetary policy shock is on impact and there is no hump-shape. Firms networking induces strategic complementarity into price setting, and is thus isomorphic to prices being stickier. This makes inflation less sensitive to changes in real marginal cost by a factor of proportionality reflecting

\footnote{Christiano, Trabandt, and Walentin (2010) are able to generate a mild price puzzle in a model similar to ours without assuming backward indexation of prices. Their model also generates a non-inertial response of inflation to a productivity shock. Their model features a large degree of wage rigidity (Calvo parameter of 0.75) and full indexation of wages to lagged inflation, however. Christiano, Eichenbaum, and Trabandt (2015a) and Christiano, Eichenbaum, and Trabandt (2015b) dispense with wage rigidity altogether, combining Calvo price stickiness into a search and matching model of the labor market. The model features no backward indexation of wages to lagged inflation. While their models do generate an inertial response of inflation to a monetary policy shock relative to the inflation response to a productivity shock, and also permit the study of the behavior of key labor market variables (like the unemployment rate), they nevertheless fall short of generating a price puzzle and a hump-shaped inflation response to a policy shock. In particular, inflation responds positively on impact to an expansionary monetary policy shock and its peak response is soon thereafter in most specifications of the model in these papers.}
the share of intermediate inputs in production. The inflation response to a policy shock is then smaller and more persistent. Extended borrowing contributes to make the response of inflation very hump-shaped. Because of working capital, the nominal interest rate has a direct effect on marginal cost. This limits the initial increase in marginal cost associated with an expansionary policy shock. With firms borrowing working capital to finance the costs of all of their inputs, the impact of the nominal interest on real marginal cost is the strongest. With limited borrowing, the impact of the nominal interest rate is naturally smaller, but is stronger if working capital is required to purchase intermediate inputs than to cover wage payments. Via the Phillips Curve, a smaller increase in marginal cost keeps inflation from initially rising by as much. Since the cut in interest rates is only temporary, as the interest rate begins to rise after impact due to the expansionary effects of the policy shock, marginal cost also begins to rise, which puts upward pressure on inflation and results in hump-shaped inflation dynamics.

Empirical evidence dating back to at least Sims (1992) sometimes finds that inflation initially falls at the onset of an expansionary monetary policy shock, before rising in a hump-shaped fashion, a feature known in the literature as the “price puzzle.”3 This aspect of the inflation response at the onset of a monetary policy shock is believed to be hard to reconcile with a model in which wage and price setting is purely forward looking. Our baseline model predicts a weak decline in inflation and a short-lived fall in the price level when firms networking is combined with extended borrowing. The decline in inflation can be made stronger and the short-run fall in the price level can last longer than in our baseline model if the average waiting time between wage adjustments is made consistent with the microeconomic evidence of Barattieri, Basu, and Gottschalk (2014) and/or of the cost of capital utilization is smaller than assumed in our baseline model. A smaller utilization cost would be more in line with the parameterization in CEE (2005).4 Stickier wages mechanically limit the initial rise in marginal cost after an expansionary policy shock, which helps to keep the response of inflation down. More variable capital utilization keeps the rental rate on capital from rising as much, which also works to keep marginal cost, and hence inflation, from rising initially.

Our baseline model also implies that output responds significantly to a monetary policy shock and in a hump-shaped, inertial fashion. The response of output to a policy shock is significantly

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3We do not want to take a firm stand as to whether the so-called price puzzle is a robust empirical fact or not. Some evidence supports the existence of a price puzzle (CEE, 1999, 2005), while some other evidence can be used to question the existence of a price puzzle (Bernanke and Mihov, 1998; Normandin and Phaneuf, 2004; Romer and Romer, 2004). Carlstrom, Fuerst, and Paustian (2009) show that timing assumptions commonly used in structural VAR identification of monetary policy shocks may produce a price puzzle and an inertial response of inflation if these timing assumptions are inconsistent with the underlying economic model.

4As described later in the text, their parameterization implies that the cost of capital utilization is nearly linear. Our parameterization is more conservative than this and is more in-line with estimates from several papers which structurally estimate this parameter in a model with multiple shocks.
larger than in versions of the model without firms networking and extended borrowing. We find
that the half-life of output conditional on a monetary shock is fourteen quarters, or three and
a half years. This is substantially larger than the output half-life in a model without extended
borrowing and firms networking, and is also higher than the half-life in a version of the model
with backward indexation. Although wage and price setters are purely forward-looking, our model
is therefore not prone to the criticism raised by Chari et al. (2000) concerning the inability of
general equilibrium models with nominal rigidities to deliver large contract multipliers for output
conditional on monetary policy shocks.

Interestingly, our model is able to deliver these results of a persistent and hump-shaped response
of inflation, and a large and persistent response of output, without assuming counterfactually
long waiting times between wage and price adjustments. In our baseline model, the median time
waiting time between wage and price adjustments is 5.1 months, which is broadly consistent with
the evidence in micro data for price setting in Bils and Klenow (2004).\(^5\) The assumed median
duration between wage changes is similar to the macro estimates reported in CEE (2005) and Altig
et al. (2011), and is actually somewhat conservative with respect to the micro evidence reported in

Another set of substantive findings concerns the cyclical behavior of markups in our model. The
evidence in Galí, Gertler and López-Salido (2007) and Nekarda and Ramey (2013) suggests that
the price markup is either mildly procyclical or acyclical unconditionally. Furthermore, according
to Nekarda and Ramey, the price markup responds positively to a negative shock to the nominal
interest rate. Galí et al. (2007) also provide evidence of a strongly countercyclical labor wedge.
With a mildly procyclical or acyclical price markup, a countercyclical labor wedge requires that
the wage markup also is countercyclical.

A procyclical price markup runs counter to the conventional wisdom from textbook New Keynes-
sian models that a countercyclical markup is the key transmission mechanism of aggregate demand
shocks (e.g. Woodford, 2003, 2011). In the basic New Keynesian model, prices are sticky and wages
are perfectly flexible, so marginal cost responds more to an expansionary policy shock than the
aggregate price index. As a result, the price markup is strongly countercyclical at the onset of
a monetary policy shock. Assuming the coexistence of price and wage rigidity in the absence of
firms networking and working capital will not generate a procyclical price markup, regardless of
whether or not backward indexation is included in our model. In fact, we find that without firms

\(^5\) Cogley and Sbordone (2008) focus on evidence about the median waiting time of price adjustments which is 5.5
months in Bils and Klenow (2004) once sales price changes are removed.
networking and working capital, the correlation between the price markup and output based on alternative measures is always close to −1.0.

By stark contrast, our baseline model predicts a mildly procyclical price markup conditioning on a monetary shock. The correlation between first-differences of the price markup and output is about 0.4, which is close to the unconditional correlation reported in Galí, Gertler and López-Salido (2007) and Nekarda and Ramey (2013). Measured in HP-filtered log-levels, we also find a procyclical price markup conditional on a policy shock, although the correlation is not as high as in first differences. Meanwhile, the wage markup and the labor wedge are both strongly countercyclical. Unlike the cyclicality of the price markup, the cyclical behavior of the wage markup and labor wedge are not strongly affected by firms networking and working capital. Combining firms networking with limited borrowing financing the purchases of intermediate goods only produces a correlation between first-differences of the price markup and output which is 0.32, and one based on HP-filtered log-levels which is -0.06. The corresponding correlations with limited borrowing instead covering only wage payments are -0.04 and -0.62, respectively.

Our last substantive finding concerns the unconditional first-order autocorrelation of the first difference of inflation. This correlation is -0.29 in US data for the years 1960-2015. We augment the model to include a TFP shock. Our model predicts a non-inertial response of inflation to a TFP shock consistent with evidence reported elsewhere in the VAR literature. The autocorrelation of the first difference of inflation is positive and mild at 0.29 conditional on the monetary policy shock and weakly negative conditional on the TFP shock at −0.11. Unconditionally, our baseline parameterization of these shock processes results in an autocorrelation of the first difference of inflation of −0.1, which is qualitatively in-line with the autocorrelation of −0.29 observed in the data. For point of comparison, we show that a model without firms networking and working capital but with full backward indexation of prices and wages generates a positive autocorrelation of the first difference of inflation unconditionally of about 0.48, which is strongly at odds with the data. Meanwhile, a model without firms networking but with backward indexation and working capital financing the wage bill as in Christiano, Eichenbaum and Evans (2005) produces an autocorrelation of the first difference of inflation of 0.52 when both monetary policy and TFP shocks drive business cycle fluctuations. As we later show, both models predict a high positive autocorrelation of the first difference of inflation conditioned on a monetary policy shock and one which is also quite quite positive conditioned on the TFP shock.

The remainder of the paper is organized as follows. Section 2 lays out our medium-scale DSGE model and discusses our calibration. Section 3 presents results for inflation and output dynamics,
the price puzzle, the cyclicality of the price markup, and the autocorrelation of the first difference of inflation. Section 4 contains concluding remarks.

2 A Medium-Scale DSGE Model with Firms Networking and Extended Borrowing

We propose a medium-scale DSGE model in the spirit of CEE (2005). It includes nominal rigidities in the form of Calvo wage and price contracts, habit formation in consumption, investment adjustment costs, variable capital utilization, and a Taylor rule. We augment the model to include firms networking and an extended working capital or cost channel. The subsections below lay out the decision problems of the relevant model actors. The full set of conditions characterizing the equilibrium are shown in the Appendix.

2.1 Good and Labor Composites

There is a continuum of firms, indexed by \( j \in (0, 1) \), producing differentiated goods with the use of a composite labor input. The composite labor input is aggregated from differentiated labor skills supplied by a continuum of households, indexed by \( h \in (0, 1) \). Differentiated goods are bundled into a gross output good, \( X_t \). Some of this gross output good can be used as a factor of production by firms. Net output is then measured as gross output less intermediate inputs. Households can either consume or invest the final net output good. The composite gross output and labor input are:

\[
X_t = \left( \int_0^1 X_t(j)^{\frac{\theta - 1}{\theta}} dj \right)^{\frac{1}{\theta - 1}},
\]

\[
L_t = \left( \int_0^1 L_t(h)^{\frac{\sigma - 1}{\sigma}} dh \right)^{\frac{1}{\sigma - 1}}.
\]

The parameters \( \theta > 1 \) and \( \sigma > 1 \) denote the elasticities of substitution between goods and labor, respectively. The demand schedules for goods of type \( j \) and labor of type \( i \) respectively are:

\[
X_t(j) = \left( \frac{P_t(j)}{P_t} \right)^{-\theta} X_t \quad \forall j,
\]

\[
L_t(h) = \left( \frac{W_t(h)}{W_t} \right)^{-\sigma} L_t \quad \forall h.
\]

The aggregate price and wage indexes are:

\[
P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj,
\]

\[
P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj,
\]
\[ W_t^{1-\sigma} = \int_0^1 W_t(h)^{1-\sigma} dh. \] (6)

2.2 Households

There is a continuum of households, indexed by \( h \in (0, 1) \), who are monopoly suppliers of labor. They face a downward-sloping demand curve for their particular type of labor given in (4). Following Calvo (1983), each period, there is a fixed probability, \( (1-\xi_w) \), that households can adjust their nominal wage, with \( 0 \leq \xi_w < 1 \). Non-updated wages may be indexed to lagged inflation via the parameter \( \zeta_w \in [0, 1] \). As in Erceg, Henderson, and Levin (2000), we assume that utility is separable in consumption and labor. State-contingent securities insure households against idiosyncratic wage risk arising from staggered wage setting. With this setup, households are identical along all dimensions other than labor supply and nominal wages. We therefore suppress dependence on \( h \) except for choice variables related to the labor market.

The problem of a particular household is to optimize the present discounted value of flow utility subject to a flow budget constraint, (8), a law of motion for physical capital, (9), the demand curve for labor, (10), and a constraint describing the Calvo wage setting process, (11):

\[
\max_{C_t, L_t(h), W_t(h), K_{t+1}, B_{t+1}, I_t, Z_t} \beta^t \sum_{t=0}^{\infty} \beta^t \left( \ln (C_t - bC_{t-1}) - \eta \frac{L_t(h)^{1+\chi}}{1+\chi} \right)
\]

s.t.

\[
P_t (C_t + I_t + a(Z_t)K_t) + \frac{B_{t+1}}{1+i_t} \leq W_t(h)L_t(h) + R^k_t Z_t K_t + \Pi_t + T_t + B_t.
\] (8)

\[
K_{t+1} = \left( 1 - S \left( \frac{I_t}{I_{t-1}} \right) \right) I_t + (1-\delta)K_t.
\] (9)

\[
L_t(h) = \left( \frac{W_t(h)}{W_t} \right)^{-\sigma} L_t.
\] (10)

\[
W_t(h) = \begin{cases} W_t^*(h) & \text{w/ prob } 1 - \xi_w \\ (1 + \pi_{t-1})^{\xi_w} W_{t-1}(h) & \text{otherwise} \end{cases}.
\] (11)

\( P_t \) is the nominal price of goods, \( C_t \) is consumption, \( I_t \) is investment, \( K_t \) is the physical capital stock, and \( Z_t \) is the level of capital utilization. \( W_t(h) \) is the nominal wage paid to labor of type \( h \), and \( R^k_t \) is a common rental price on capital services (the product of utilization and physical capital). \( \Pi_t \) represents distributed dividends from firms and a financial intermediate, which households take as given. \( T_t \) denotes lump sum transfers. \( B_t \) is the stock of nominal bonds with which the household enters the period. The nominal interest on these bonds is \( i_t \). \( a(Z_t) \) is a resource cost of utilization,
satisfying $a(1) = 0, a'(1) = 0, \text{ and } a''(1) > 0$. This resource cost is measured in units of physical capital. $S \left( \frac{b}{\tau_{t-1}} \right)$ is an investment adjustment cost, satisfying $S(1) = 0, S'(1) = 0, \text{ and } S''(1) > 0$. $0 < \beta < 1$ is a discount factor, $0 < \delta < 1$ is a depreciation rate, and $0 \leq b < 1$ is a parameter for internal habit formation. $\chi$ is the inverse Frisch labor supply elasticity and $\eta$ is a scaling parameter on the disutility from labor. It is straightforward to show that all households given the opportunity to change their wage will adjust to a common reset wage, $W_t^*$. 

### 2.3 Firms

The production function for a typical producer $j$ is:

$$X_t(j) = \max \left\{ \Gamma_t(j)^{\phi} \left( \hat{K}_t(j)^{\alpha} L_t(j)^{1-\alpha} \right)^{1-\phi} - F, 0 \right\} \tag{12}$$

The parameter $F$ is a fixed cost, and production is required to be non-negative. We choose the value of $F$ such that profits are zero in steady state, which allows us to ignore entry and exit. $\Gamma_t(j)$ is the amount of intermediate inputs, and $\phi \in (0, 1)$ is the intermediate input share. Intermediate inputs come from aggregate gross output, $X_t$. $\hat{K}_t(j)$ is capital services (the product of physical capital and utilization), while $L_t(j)$ is labor input.

A firm gets to choose its price, $P_t(j)$, as well as quantities of the intermediate input, capital services, and labor input. It is subject to Calvo pricing, where each period there is a $(1 - \xi_p)$ probability that a firm can re-optimize its price, with $0 \leq \xi_p < 1$. Non-updated prices may be indexed to lagged inflation at $\zeta_p \in [0, 1]$. In other words, a firm’s price satisfies:

$$P_t(j) = \begin{cases} P_t^*(j) & \text{w/ prob } 1 - \xi_p \\ (1 + \pi_{t-1})^{\zeta_p} P_{t-1}(j) & \text{otherwise} \end{cases} \tag{13}$$

An updating firm will choose its price to maximize the present discounted value of flow profit, where discounting is by the stochastic discount factor of households as well as the probability that a price chosen today will still be in effect in the future. It is straightforward to show that all firms given the ability to change their price will adjust to a common reset price, $P_t^*$. Regardless of whether a firm can re-optimize its price, it will always choose inputs so as to minimize cost, subject to the constraint of meeting demand at its price. A key assumption is that firms must finance some or all of their variable inputs through intra-period loans from a financial intermediary. The financial intermediary returns the interest earned on these loans to the household.
lump sum. The cost-minimization problem of a typical firm is:

$$\min_{\Gamma_t, K_t, L_t} (1 - \psi_T + \psi_T(1 + i_t)) P_t \Gamma_t + (1 - \psi_K + \psi_K(1 + i_t)) R_t^K \overline{K_t} + (1 - \psi_L + \psi_L(1 + i_t)) W_t L_t$$  \hspace{1cm} (14)$$

subject to:

$$\Gamma_t^\phi \left( \overline{K_t}^\alpha L_t^{1-\alpha} \right)^{1-\phi} - F \geq \left( \frac{P_t(j)}{P_t} \right)^{-\phi} X_t.$$  \hspace{1cm} (15)$$

Here $$\psi_l$$, $$l = \Gamma, K, L$$, is the fraction of payments to a factor that must be financed at the gross nominal interest rate, $$1 + i_t$$. With $$\psi_l = 0$$ for all $$l$$, firms do not have to borrow to pay any of their factors. The use of working capital may be limited. When used to finance only wage payments as in CEE (1997; 2005) and Ravenna and Walsh (2006), we set $$\psi_T = \psi_K = 0$$ and $$\psi_L = 1$$, a case to which we refer as LBW. When used to finance only the purchase of intermediate goods, a case we refer to as LBI, we set $$\psi_L = \psi_K = 0$$ and $$\psi_T = 1$$. Assuming $$\psi_l = 1$$ for all $$l$$ means that all factor payments are financed through working capital, so that the factor prices relevant for firms are the product of the gross nominal interest rate and the factor price. We refer to this case as extended borrowing (EB). To economize on notation, we define $$\Psi_{l,t} = (1 - \psi_l + \psi_l(1 + i_t))$$ for $$l = \Gamma, K, L$$.

Applying some algebraic manipulations to the first order conditions for the cost-minimization problem yields an expression for real marginal cost, $$v_t \equiv \frac{V_t}{P_t}$$, which is common across all firms:

$$v_t = \overline{\phi} \Psi_{l,t}^\phi \left( \Psi_{K,t} r_t^K \right)^{\alpha(1-\phi)} \left( \Psi_{L,t} w_t \right)^{(1-\alpha)(1-\phi)},$$  \hspace{1cm} (16)$$

with $$\overline{\phi} \equiv \frac{1}{\phi} \left( \frac{1}{\overline{\phi}} \right)^{1-\phi} \left( \frac{1}{\alpha} \right)^{1-\phi} \left( \frac{\alpha}{1-\alpha} \right)^{(1-\alpha)(1-\phi)}$$. The variables $$r_t^K$$ and $$w_t$$ are the real rental rate on capital services and the real wage for labor, respectively. This general expression encompasses several special cases. In a model where both firms networking ($$\phi = 0$$) and financial intermediation ($$\Psi_{l,t} = 1$$ for all $$l$$) are excluded, the expression for real marginal cost reduces to:

$$v_t = \left( \frac{1}{1-\alpha} \right)^{1-\alpha} \left( \frac{1}{\alpha} \right)^{\alpha} \left( r_t^K \right)^{\alpha} \left( w_t \right)^{1-\alpha}.$$  \hspace{1cm} (17)$$

For the case of firms networking and limited borrowing, in which case working capital covers only wage payments (LBW), real marginal cost is:

$$v_t = (1 + i_t)^{(1-\alpha)(1-\phi)} \overline{\phi} \left( r_t^K \right)^{\alpha(1-\phi)} \left( w_t \right)^{(1-\alpha)(1-\phi)}.$$  \hspace{1cm} (18)$$
The real marginal cost expression in Christiano, Eichenbaum Evans (2005) is obtained by setting $\phi = 0$ in (18). With firms networking and limited borrowing with working capital financing only intermediate goods (LBI), real marginal cost is:

$$v_t = (1 + i_t)^{\phi\phi} \left( \frac{r^k_t}{w_t} \right)^{1-\phi} w_t^{(1-\alpha)(1-\phi)}. \quad (19)$$

Combining firms networking and extended borrowing (EB) gives the expression:

$$v_t = (1 + i_t)^{\phi\phi} \left( \frac{r^k_t}{w_t} \right)^{1-\phi} w_t^{(1-\alpha)(1-\phi)}. \quad (20)$$

According to these expressions, once our model accounts for borrowing, either in a limited or extended form, the nominal interest rate directly impacts real marginal cost. More importantly, the impact of the nominal interest rate increases with the extent of required borrowing. With working capital financing only the wage bill, the impact of the nominal interest on the real marginal cost is determined by the exponent $(1 - \alpha)(1 - \phi)$. With working capital financing only the purchase of intermediate goods, the impact of the nominal rate is determined by $\phi$ which is larger than $(1 - \alpha)(1 - \phi)$. Finally, with extended working capital, the exponent on $(1 + i_t)$ is one and is thus greater than in the last two cases with limited borrowing.

### 2.4 Monetary Policy

Monetary policy follows a Taylor rule:

$$\frac{1 + i_t}{1 + i} = \left( \frac{1 + i_{t-1}}{1 + i} \right)^{\rho_i} \left[ \left( \frac{\pi_t}{\pi} \right)^{\alpha_{\pi}} \left( \frac{Y_t}{Y_{t-1}} \right)^{\alpha_{y}} \right]^{1-\rho_i} \epsilon^*_t \quad (21)$$

The nominal interest rate responds to deviations of inflation from an exogenous steady-state target, $\pi$, and to output growth, $\frac{Y_t}{Y_{t-1}}$. The exogenous variable $\epsilon^*_t$ is an i.i.d. normal process, with a zero mean and a finite known variance $\sigma_t$. The parameter $\rho_i$ governs the smoothing-effect on nominal interest rates while $\alpha_{\pi}$ and $\alpha_{y}$ are control parameters. We restrict attention to parameter configurations resulting in a determinate rational expectations equilibrium.

### 2.5 Aggregation

Given properties of Calvo (1983) price and wage setting, aggregate inflation and the real wage evolve according to:

$$1 = \xi_p \pi^\theta \pi_{t-1} \xi_{p^*}^{1-\theta} + (1 - \xi_p) \left( p^*_t \right)^{1-\theta} \quad (22)$$
\[ w_t^{1-\sigma} = \xi_w \left( \frac{w_{t-1} \pi_{t-1} \pi_t}{\pi_t} \right)^{1-\sigma} + (1 - \xi_w) (w^*_t)^{1-\sigma} \] (23)

The notation here is that \( \pi_t \equiv \frac{P_t}{P_{t-1}} \) is aggregate gross inflation, \( p^*_t \equiv \frac{P^*_t}{P_t} \) is the relative reset price, \( w_t \equiv \frac{W_t}{P_t} \) is the real wage, and \( w^*_t \equiv \frac{W^*_t}{P_t} \) is the real reset wage. Market-clearing for capital services, labor, and intermediate inputs requires that \( \int_0^1 \tilde{K}_t(j) dj = \tilde{K}_t, \int_0^1 L_t(j) dj = L_t, \) and \( \int_0^1 \Gamma_t(j) dj = \Gamma_t. \) This means that aggregate gross output can be written:

\[ s_t X_t = \Gamma_t^\phi \left( \tilde{K}_t^{\alpha} L_t^{1-\alpha} \right)^{1-\phi} - F \] (24)

where \( s_t \) is a price dispersion variable that can be written recursively:

\[ s_t = (1 - \xi_p) p^* - \theta + \xi p \pi - \xi p \pi^{-1} \pi s_{t-1} \] (25)

Using the market-clearing conditions, the aggregate factor demands can be written:

\[ \Gamma_t = \phi v_t \Psi_{\Gamma}^{-1} (X_t + F) \] (26)

\[ \tilde{K}_t = \alpha (1 - \phi) \frac{\Psi_t}{\Psi_t K_t} (X_t + F) \] (27)

\[ L_t = (1 - \alpha) (1 - \phi) \frac{\Psi_t}{\Psi_t L_t} (X_t + F) \] (28)

Aggregate net output, \( Y_t, \) is gross output minus intermediate input:

\[ Y_t = X_t - \Gamma_t \] (29)

Integrating over household budget constraints yields the aggregate resource constraint:

\[ Y_t = C_t + I_t + a(Z_t) K_t \] (30)

### 2.6 Functional Forms

The resource cost of utilization and the investment adjustment cost function have the following functional forms:

\[ a(Z_t) = \gamma_1 (Z_t - 1) + \frac{\gamma_2}{2} (Z_t - 1)^2 \] (31)
$$S \left( \frac{I_t}{I_{t-1}} \right) = \frac{\kappa}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2$$

where $\gamma_2 > 0$ is a free parameter; as $\gamma_2 \to \infty$ utilization becomes fixed at unity. $\gamma_1$ must be restricted so that the optimality conditions are consistent with the normalization of steady state utilization of 1. $\kappa \geq 0$ is a free parameter. The functional form for the investment adjustment cost is standard in the literature (e.g. see Christiano et al., 2005).

2.7 Calibration

We use the calibration summarized in Table 1. Some parameter values, like $\beta$, $b$, $\eta$, $\chi$, $\delta$ and $\alpha$ are standard in the literature. Others require some explanations.

The parameter governing the size of investment adjustment costs $\kappa$ is 5, which is somewhat lower than the estimate in Altig et al. (2011) but higher than the estimate in CEE (2005). The parameter on the squared term in the utilization adjustment cost is set to $\gamma_2 = 0.05$. This is broadly consistent with the evidence in Basu and Kimball (1997) and Dotsey and King (2006)), and is middle range between Justiniano, Primiceri, and Tambaletti (2010, 2011), who estimate this parameter to be about 0.15, and CEE (2005), who fix this parameter at 0.00035. Later, we assess the sensitivity of the price puzzle to the value of this parameter. The parameter $\theta$ is the elasticity of substitution between differentiated goods and is set at 6. This implies a steady-state price markup of 20 percent, which is consistent with Rotemberg and Woodford (1997). The steady-state price markup is used in computing $\phi$ as we discuss below. The parameter $\sigma$ is the elasticity between differentiated labor skills and is also set at 6 (e.g., see Huang and Liu, 2002; Griffin, 1992).

The Calvo probabilities for wage and price non-reoptimization both take a value of 0.66. Bils and Klenow (2004) report that the median duration of prices is 5.5 months after removing sales price changes. For a purely forward-looking Calvo model with no backward indexation, Cogley and Sbordone (2008) approximate the median waiting time of a price change by $-\ln(2)/\ln(\xi_p)$. Setting $\xi_p = 0.66$ therefore implies a median duration of prices of 5.1 months, which is broadly consistent with the evidence reported in Bils and Klenow (2004).

Our calibration of $\xi_w = 0.66$ implies an average waiting time between wage adjustments of 3 quarters. This is somewhat higher than the macro estimate of 0.64 reported in CEE (2005), but somewhat lower than the estimate of 0.71 in Altig et al. (2011). In some sensitivity analysis, we also look at the impact of a higher average duration of wage contracts. For this, we consider the evidence in Barattieri, Basu, and Gottschalk (2014), who analyze micro-data for the U.S. economy.

$^6$CEE set $\frac{\gamma_2}{\gamma_1} = 0.01$; given the parameterization of $\gamma_1$ to be consistent with steady state utilization of unity, this implies $\gamma_2 = 0.00035$. 
They find that the average quarterly probability of a wage change lies between 0.211 and 0.266, which would imply a value of $\xi_w$ in the range of 0.75-0.80. Justiniano et al. (2010, 2011) also report higher estimates of $\xi_w$ in this range using a New Keynesian model augmented with several more shocks, but without firms networking or a working capital channel.

The parameter $\phi$ measures the share of payments to intermediate inputs in total production. Nakamura and Steinsson (2010) summarize information from the 2002 U.S. Input–Output Table published by the Bureau of Economic Analysis. They document that the weighted average revenue share of intermediate inputs in the U.S. private sector using Consumer Price Index (CPI) expenditure weights was roughly 52 percent in 2002. The cost share of intermediate inputs must equal the revenue share times the markup. Since our calibration of $\theta$ implies a steady state price markup of 1.2, this then implies $\phi = 0.624$. This is lower than $\phi = 0.7$ in Nakamura and Steinsson because they assume a lower value of $\theta$, implying a steady-state price markup of 1.33.\(^7\)

The parameters of the Taylor rule include the smoothing parameter set at 0.8, the coefficient on inflation at 1.5, and the coefficient on output growth at 0.2. The standard deviation of the monetary policy shock $\sigma_r$ is set at 0.002, which is consistent with the estimates reported in Justiniano et al. (2010, 2011). We assume that there is zero trend inflation, $\pi = 0$. As a baseline we also assume that there is no backward indexation of prices or wages to lagged inflation, i.e. $\zeta_p = \zeta_w = 0$.

### 3 Results

In this section we present results from the model. We take our baseline model to be the specification in which there is firms networking (FN) and extended borrowing (EB), in which all three factors of production must be financed through working capital. We focus on impulse responses and second moments, and examine the roles that different model features play in generating the results. Subsection 3.1 focuses on the dynamic responses of output and inflation to a monetary policy shock. Subsection 3.2 focuses on the cyclical behavior of the price and wage markups and of the labor wedge conditional on monetary policy shocks. In Subsection 3.3 we examine the extent to which our model can generate a short-run decline in inflation following an expansionary monetary policy shock and which model features play a role in that. Subsection 3.4 examines the implications of our model for the unconditional autocorrelation of the first difference of inflation in relation to models with backward indexation.

\(^7\)Note that Basu (1995) and Bergin and Feenstra (2000) argue for values of $\phi$ between 0.8 and 0.9. Huang, Liu, and Phaneuf (2004) favor a value of 0.7. Rotemberg and Woodford (1995), Chari, Kehoe, and McGrattan (1996), and Woodford (2003, Ch. 3) use values closer to 0.5. Thus, assuming $\phi = 0.624$ seems to strike a middle ground.
3.1 Inflation and Output Dynamics

Figure 1 plots the model impulse responses of output, inflation, and the price level to a one standard deviation expansionary monetary policy shock (i.e. a negative shock to the Taylor rule). The solid lines show the responses in our baseline model. For point of comparison, we also present impulse responses under three alternative specifications. The first two gauge the relative contribution of EB and FN in generating our main findings. The dotted lines show responses in which there is no extended borrowing (nor limited borrowing, so that none of the factors of production must be financed through working capital, i.e. $\psi_T = \psi K = \psi L = 0$). The dashed lines show the responses in which there is no firms networking (i.e. $\phi = 0$). The third specification is one where there is no extended borrowing and no firms networking, but in which prices and wages are fully indexed to lagged inflation (i.e. $\zeta_p = \zeta_w = 1$); the responses are represented by dashed lines with “+” markers.

In our baseline model output rises by about 0.2 percent on impact of the monetary policy shock. This jump is roughly half the magnitude of the peak output response, which is 0.4 percent and occurs about four quarters subsequent to the shock. The response of output is highly persistent, being positive more than five years after the shock; it also displays a hump-shaped pattern. The impact response of inflation is slightly negative, a point to which we return in more depth below; the inflation response then turns positive in the next period and reaches its peak response after about four quarters. Like the output response, the inflation impulse response to the policy shock is quite persistent. Consistent with the behavior of inflation, the price level jumps down on impact but then slowly and persistently rises.

When there is no working capital at all (dotted lines), the impulse response of inflation is largest on impact, and exhibits no hump-shape. Thus, working capital is needed to generate a hump-shaped inflation response. The response of output is also somewhat smaller compared to our baseline model. If instead there is no firms networking but all factors are financed via working capital (dashed lines), the response of inflation is hump-shaped, but is positive on impact and the peak response occurs roughly three quarters subsequent to the shock. Thus, the short-run response of inflation significantly exceeds that in the baseline model. The response of inflation is also less persistent. Abstracting from firms networking implies that the slope of the New Keynesian Phillips Curve is steeper relative to our baseline model, making inflation more responsive to the monetary policy shock and lowering inflation persistence. As a result, the response of output is also significantly smaller and less persistent than in the baseline model. Without EB and FN (responses not reported), the peak response of inflation is on impact, with inflation jumping up substantially, and there is no hump-shaped pattern. The impulse response of output is smaller on impact and at
all horizons. Though it follows a hump-shaped pattern, the peak output responses occurs sooner relative to the impact effect when compared to the baseline model.

The dashed lines with “+” markers take the “standard” New Keynesian model without EB and FN and modify it so that both prices and wages are fully indexed to one period lagged inflation (i.e. $\zeta_p = \zeta_w = 1$). This kind of specification has been advanced in the literature as a way to generate more inertia in the response of inflation to a policy shock. This specification does result in a hump-shaped response of inflation, but the impact effect on inflation is still positive, compared to our baseline model which is capable of delivering a short-run decline in inflation. The inflation response also reverts to zero from its peak more quickly than in the baseline model which does not feature any indexation. The inclusion of backward indexation makes the output response to the policy shock smaller and less persistent.

The reasons why a model with backward indexation can produce a hump-shaped response of inflation to a monetary policy shock are well understood. But how is it that our model, without wage and price indexation, can also generate hump-shaped inflation dynamics? The two key model ingredients giving rise to this pattern are firms networking and a working capital channel. These two channels can be seen in equation (20), which is the expression for real marginal cost in our model. Because working capital results in the nominal interest rate having a direct effect on marginal cost, it works to limit the increase in marginal cost associated with an expansionary policy shock. Via the traditional Phillips Curve, a smaller increase (or a decrease) in marginal cost keeps inflation from initially rising by as much. Because the cut in interest rates is only temporary, as the interest rate starts to rise after impact, marginal cost begins to rise, which puts upward pressure on inflation and can result in hump-shaped inflation dynamics. Firms networking works through a similar channel. Positive values of $\phi$ limit the sensitivity of marginal cost to fluctuations in factor prices, and therefore allow output to expand by more without marginal cost (and hence inflation) rising by much.

What happens if working capital serves to finance the costs of fewer inputs than in our baseline model? Figure 2 compares the responses of output, inflation, and real marginal cost and its components when working capital financing the costs of all inputs (solid lines), the cost of intermediate inputs only (dotted lines), and the cost of labor only (dashed lines). The three models include firms networking. The greater the extent of working capital is, the lower the response of inflation on impact of a monetary policy shock and the more persistent the response is. Correspondingly, the response of output is stronger and more persistent with more inputs financed via working capital. With working capital financing more inputs, the response of real marginal cost becomes more
negative despite the fact that the responses of the real wage and the real rental rate become larger
due to a larger expansion in output.

So the question is: what factor drives the greater decline in the real marginal cost accompanying
the model with EB relative to the models with LBI and LBW? The answer to this question is easily
understood by comparing the alternative expressions for real marginal in equations (20), (19) and
(18). In the baseline model, the nominal interest rate has a proportional impact on real marginal
cost. In the model where only the purchase of intermediate goods is financed through working
capital, equation (19) shows that the effect of the nominal rate on real marginal cost is determined
by the exponent $\phi = 0.625$, which is lower than in the model with EB. When working capital is used
to finance the wage bill only, equation (18) shows that the nominal rate affects the real marginal
cost to an extent governed by the exponent $(1 - \alpha)(1 - \phi) = 0.25$, which is 2.5 times smaller than
in the model with LBI and 4 times smaller than in the model with EB.

Table 2 presents some statistics summarizing the dynamics of inflation and output conditioned
on monetary policy shocks. It shows autocorrelation coefficients for inflation at different lag lengths.
In the baseline model the first order autocorrelation of inflation is 0.92. Inflation is highly persist-
tent, with an autocorrelation coefficient at a one year lag of more than 0.5. The autocorrelation
coefficients of inflation are higher (by 0.1 or more) at all lags in the base model relative to the
version of the model with no working capital and no firms networking. The model without work-
ing capital and firms networking, but augmented with full backward indexation, produces a first
order autocorrelation of inflation that is slightly higher than our baseline model (0.95 vs 0.92),
but the autocorrelation at lags higher than 4 is higher in the baseline model than in the backward
indexation model (0.53 vs 0.49 at a four quarter lag and 0.40 versus 0.32 at a five quarter lag).

We also calculate the half-life of output by finding the number of quarters it takes for the
response of output to equal one-half its impact response (rounded to the nearest integer). In the
baseline model the half-life of output is 14 quarters, or three and a half years. Even though price
and wage setting is purely forward-looking in the model, it is not prone to the criticism of Chari,
Kehoe, and McGrattan (2000) that nominal rigidities are not sufficient to generate a large contract
multiplier for output in a general equilibrium framework with intertemporal links. In the model
with no working capital and no firms networking, the half-life of output is still substantial but half
of a year shorter than in the baseline model at 12 quarters. The half-life of output is substantially
lower in the model with full backward indexation of prices and wages, with a half-life of only one
and a half years.
3.2 Cyclical Markups and the Labor Wedge

The basic transmission mechanism by which positive demand shocks raise output in the textbook New Keynesian model is via a countercyclical price markup over marginal cost (see, e.g., Woodford, 2003, 2011). Nekarda and Ramey (2013) have recently challenged the empirical relevance for this transmission mechanism. In particular, they empirically find that the price markup is procyclical unconditionally. A similar finding has previously been reported by Galí, Gertler and López-Salido (2007). Nekarda and Ramey have also shown that the price markup is procyclical conditional on an expansionary monetary policy shock.

The main focus of this subsection is to examine the implications of our model for the cyclical behavior of the price markup. We show that the response of the price markup to an expansionary monetary policy is quite sensitive to assuming firms networking and working capital either in its extended form or its limited form covering intermediate inputs only. In fact, we show that the price markup switches from strongly countercyclical without firms networking and extended working capital to mildly procyclical with these features included in the model. Accounting for backward indexation without these features does not produce a procyclical price markup conditioned on a monetary policy shock. In fact, without firms networking and working capital, the correlation between output and the price markup driven by a monetary policy shock is close to \(-1.0\), with or without indexation.

Furthermore, because our model includes both sticky wages and sticky prices, we also look at its implications for the behavior of the wage markup and the labor wedge. The labor wedge is the sum of the two equilibrium markups, that of price over marginal cost and that of real wages over the marginal rate of substitution. Galí, Gertler and López-Salido (2007) report evidence that the wage markup and labor wedge are both very countercyclical.

Panel A of Figure 3 plots the impulse responses of the price markup, Panel B the response of the wage markup, and Panel C the response of the labor wedge to an expansionary monetary policy shock for different specifications of our model. The solid lines show the responses in our baseline model. The dotted lines are for the responses from the model that features firms networking and LBI. The dashed-line responses are from the model with firms networking and LBW. Finally, the responses with the dashed lines marked with “+” are from the model that excludes both firms networking and financial intermediation but includes full indexation of nominal wages and prices to the previous quarter’s rate of inflation.

A striking result is that the response of the price markup varies quite significantly among alternative model specifications. This is not the case for the the wage markup or the labor wedge. One
sees that in our baseline model the price markup initially rises and remains positive for about four quarters, after which time it goes slightly negative before returning to trend. In other words, our model generates a procyclical price markup conditional on a monetary policy shock, at least for a few quarters. The response of the price markup in our model is qualitatively similar to the conditional procyclicality Nekarda and Ramey (2013) estimate (see Figure 4 in their paper). Without firms networking and working capital, the response of the price markup is negative. Consonant with the basic intuition from the textbook sticky price New Keynesian model with flexible wages and without capital, the markup is very countercyclical conditional on the expansionary policy shock in this version of the model.

The dotted lines in Figure 3 show that insofar as working capital is used to finance intermediate goods, the response of the price markup will remain positive in the short run. From the dashed line price markup response, we see that things are quite different if working capital serves to finance the wage bill only, which is generally the case in existing DSGE models with financial intermediation. Then, the response of the price markup is weak and positive only for one period and turns negative after.

The dashed line with “+” markers plots the impulse response of the price markup in a version of the model in which there is neither firms networking nor working capital, but in which prices and wages are fully indexed to lagged inflation. Though full indexation alone is capable of generating hump-shaped inflation dynamics (see Figure 1), it does little to change the dynamic response of the price markup when the model abstracts from firms networking and working capital. The response of the markup is negative for about five periods and then turns weakly positive, implying a markup which is strongly countercyclical conditionally.

Panel B of Figure 3 plots the impulse responses of the wage markup. One notes that the negative responses of the wage markup to an expansionary monetary policy shock are almost identical in models with firms networking and working capital, whether borrowing is extended or limited. The dashed line with “+” markers shows that in a model without firms networking and working capital but with indexation, the response of the wage markup is negative for about five periods and then turns slightly positive before returning to zero. Panel C of Figure 3 plots the impulse responses of the labor wedge. The negative responses of the labor wedge closely follow those of the wage markup.

Table 3 presents some statistics for the cyclicality of the price markup, the wage markup, and the labor wedge with different model specifications. We measure the cyclicality of markups and the labor wedge by the correlation with real GDP. For this, we use three different filtering devices – first differences, log-levels, and HP-filtered log-levels. In the case of the price markup, we also
include for a point of comparison the cyclicalities of the price markup estimated by Nekarda and Ramey (2013). However, some caution is in order when making comparisons between the model and their data, because their cyclicalities are unconditional whereas ours are conditional on a monetary policy shock. Nevertheless, the comparisons are revealing, so we have chosen to include them.

Regardless of filtering method, our baseline model generates a procyclical price markup conditional on a monetary policy shock. The correlation between the first log differences of the price markup and output is 0.42, which is very close the unconditional correlation estimated by Ramey and Nekarda (2013) of 0.50. In log-levels the correlation in the model is smaller but nevertheless still positive at 0.09. When the series are HP-filtered the correlation between the markup and output is 0.16. This is a bit smaller than what Nekarda and Ramey (2013) report, but is qualitatively in-line with their results.

Both firms networking and extended borrowing are needed for these results. Removing extended borrowing from the model results in a correlation between output and the price markup which is close to −1.0, and this no matter what the filtering method is. With extended borrowing but without firms networking, the correlation is 0.24 with first differences, −0.48 with log-levels and −0.3 with HP-filtered log-levels. Therefore, it is the combination of firms networking and extended working capital that produces a procyclical price markup.

The model with firms networking and working capital financing only intermediate goods delivers a correlation between the first log differences of the price markup and output of 0.32, which is lower than in our baseline model but not too far from the unconditional correlation estimated by Ramey and Nekarda (2013). In log-levels, however, the correlation becomes weakly negative at -0.23, while in HP-filtered log-levels, the correlation is -0.06. But accounting for limited borrowing with working capital used to finance only intermediate inputs marks a significant improvement over a medium-scale macro model that excludes firms networking and working capital. The model in which working capital finances only the wage bill does not perform as well, producing a correlation between output and the price markup which is −0.04 with first log differences, −0.81 with log-levels, and −0.62 with HP-filtered log-levels, making it at odds with the evidence.

Just as it is key to generating a hump-shaped response of inflation to a policy shock, the working capital channel is the key mechanism capable of delivering a conditionally procyclical price markup. Our baseline model assumes that all factors must be fully financed via working capital, i.e. \( \psi_T = \psi_K = \psi_L = 1 \). One might wonder whether or not intermediate values of these parameters are also capable of generating a procyclical markup. In Figure 4 we plot the cyclicality of the price markup (with the three different filtering methods) for values of \( \psi \) between 0 and 1, where we assume that \( \psi_I = \psi \) for all three factors. When there is no working capital channel at all (\( \psi = 0 \),
the correlation of the markup with output is close to -1 regardless of filter. When focusing on the correlation in first differences, our model generates a positive correlation between the markup and output conditional on a policy shock for values of $\psi \geq 0.25$. The cutoff value of $\psi$ for a procyclical markup is higher when focusing on correlations in log-levels or when looking at HP filtered data. For HP filtered data, $\psi$ must be bigger than about two-thirds to generate a procyclical markup. In levels, the cutoff value of $\psi$ is roughly 0.85. In other words, while our model relies on at least some working capital channel to generate a procyclical markup conditional on a policy shock, the entirety of factor payments do not have to be financed with working capital for this result to obtain.

While the cyclical behavior of the price markup conditioned on a monetary policy shock can vary quite significantly depending on model specifications, this is not the case of the cyclical behavior of the wage markup and labor wedge. We find that the correlations between the wage markup and output are always very negative, and this no matter what filtering method is used. We also find that the labor wedge is generally more countercyclical than the wage markup. These findings about the cyclicalities of the wage markup and the labor wedge are very consistent with the evidence in Galí, Gertler and López-Salido (2007).

3.3 Short-Run Decline in Inflation: the “Price Puzzle”

Our model is capable of generating a short-run fall of inflation following an expansionary monetary policy shock rather than an increase as the standard New Keynesian model would suggest. When this fall is sizeable enough and lasts about a year, it is known in the literature as the “price puzzle.” Some empirical studies reach this finding when identifying monetary policy shocks in structural VARs (Sims, 1992; Christiano, Eichenbaum and Evans, 1999, 2005). But at the same time, other studies question the existence of a price puzzle (see our footnote 2). Although we do not want to take a firm stand as to whether a price puzzle is a robust feature of the data, we identify in this subsection some plausible conditions under which the short-run decline in inflation will be somewhat stronger and more persistent than in our baseline model.

As discussed above, our model can generate a short-run decline in inflation because of the interaction of firms networking with the working capital channel applied to all variable factors of production. However, it would be difficult to speak of a price puzzle in our baseline model considering the size and the short duration of the decline in inflation. Here we look at how sensitive our results are to changes in the parameterization of our model in some acceptable range. Figure 5 shows impulse responses of inflation and the price level under some alternative parameterizations.
of our baseline model (which includes both firms networking and working capital applied to all variable inputs). The solid lines show the responses in our baseline parameterization. The dashed line shows responses when we assume that wages are stickier than in our baseline, with $\xi_w = 0.75$ instead of 0.66. A value of $\xi_w$ in this range is consistent with the micro analysis in Barattieri, Basu, and Gottshalk (2014), and is also consistent with estimates from medium scale DSGE models with many shocks (e.g. Justiniano, Primiceri, and Tambalotti, 2010, 2011). With stickier wages, the initial fall in inflation is even greater than in our baseline parameterization, and is strong enough that the price level response does not turn positive for three quarters, and does not significantly rise for several more quarters after that. In other words, our parameterization of the wage stickiness parameter is conservative with respect to the magnitude of the short-run decline in inflation our model can generate. The intuition for this effect is straightforward. The stickier are nominal wages, the less real wages increase after a policy shock. This reinforces the effects of working capital and firms networking in keeping marginal cost from increasing, which results in a smaller initial reaction of inflation.

The dashed lines plot impulse responses with a parameterization implying a more elastic response of capital utilization. Our parameterization of $\gamma_2 = 0.05$ (the parameter which governs the squared term in the utilization cost) is a middle ground between Justiniano, Primiceri, and Tambalotti (2010, 2011), who estimate this parameter to be about 0.15, and CEE (2005), who fix this parameter at 0.00035 (in particular, their parameterization fixed $\frac{\gamma_2}{\gamma_1} = 0.01$; given the parameterization of $\gamma_1$ to be consistent with steady state utilization of unity, this implies $\gamma_2 = 0.00035$). The dashed lines show responses when we use the lower value of $\gamma_2$ consistent with CEE (2005). Like stickier wages, this also has the effect of magnifying the short-run fall in inflation, while the price level response does not turn positive for four quarters. The household’s first order condition for optimal capital utilization requires that $r^k_t = a'(Z_t) = \gamma_1 + \gamma_2(u_t - 1)$ (see the Appendix). A lower value of $\gamma_2$ has the effect of making the real rental rate, $r^k_t$, less sensitive to utilization. This has the effect of keeping the real rental rate from rising as much after an expansionary policy shock, which works to keep marginal cost down, and therefore limits the increase in inflation on impact (or in this case, magnifies the decrease in inflation on impact). In contrast to the impact effect, when capital utilization is more elastic inflation and hence the price level actually respond more positively after several quarters than our baseline specification.

### 3.4 The Autocorrelation of the First Difference of Inflation

In this subsection, we examine the ability of our baseline model to explain the autocorrelation of the first difference of inflation. When measuring inflation in the data as the first difference of the log
GDP price deflator, we find that the unconditional first order autocorrelation of the first difference of inflation for the period 1960-2015 is negative at $-0.29$. Our baseline model with firms networking and working capital for all variable inputs generates a hump-shaped impulse response of inflation to a monetary policy shock. A model without these features but with full backward indexation of prices and wages to lagged inflation can also generate a hump-shaped response of inflation. A hump-shaped impulse response function implies positive autocorrelation in first differences. So, because our baseline model is driven only by monetary policy shocks, it will generate a positive first order autocorrelation of first differenced inflation.

The first inner column of Table 4 confirms this. It shows that the first order autocorrelation of first differenced inflation is positive in our baseline model at 0.29. This Table also shows that the first order autocorrelation of the first difference of inflation in a version of the model with no working capital channel and no firms networking, but where prices and wages are both fully indexed to lagged inflation, is also positive but substantially higher than in our baseline model at 0.73.

While the primary focus of our paper is on the conditional responses to a monetary policy shock, it is of interest to explore the implications of our model conditional on a TFP shock as well. While virtually all empirical papers find that inflation responds sluggishly and in a hump-shaped fashion to a monetary policy shock, this is generally not the case conditional on a TFP shock. Galí (1999) identifies a neutral productivity shock in a structural VAR using a long run restriction. He finds that inflation falls sharply in the period of a positive productivity shock, and then reverts monotonically back to trend, with no hump-shape. Using growth accounting techniques to construct a “purified” Solow residual, Basu, Fernald, and Kimball (2006) reach a similar conclusion, finding that the price level adjusts downward quickly conditional on a technology shock.

We augment our model to include a TFP shock. For this, we augment the production function of a typical intermediate producer, (12), to include a shift term, $A_t$:

$$X_t(j) = \max \left\{ A_t \Gamma_t(j)^\phi \left( \bar{K}_t(j)^\alpha L_t(j)^{1-\alpha} \right)^{1-\phi} - F, 0 \right\}, \quad (33)$$

The exogenous variable $A_t$ is common across all firms. It obeys a stationary stochastic process with non-stochastic steady state value normalized to unity and an innovation drawn from a normal distribution with standard deviation equal to $s_A$:

$$A_t = A_{t-1}^{\rho_A} \exp \left( s_A \varepsilon_t^A \right), \quad 0 < \rho_A < 1, \quad \varepsilon_t^A \sim N(0,1). \quad (34)$$

We parameterize the shock processes as follows. We set the AR(1) parameter of the TFP shock as $\rho_A = 0.95$. Then we choose the size of the standard deviations of the monetary policy and TFP
shocks so that our baseline model generates a standard deviation of output growth of 0.0067, which is about its value in postwar U.S. data, after imposing that the TFP shock explains 75 percent of the unconditional variance of output growth and the monetary policy shock 25 percent. This gives $s_r = 0.0026$ and $s_A = 0.0094(1 - \phi) = 0.0035$.

Figure 6 plots impulse responses of inflation to a monetary policy shock and a TFP shock. We do so for two model specifications – our baseline specification (solid line) and a specification of the model with no working capital, no firms networking, but full indexation of prices and wages to lagged inflation (dashed line). Both model specifications generate a hump-shaped response of inflation to a monetary policy shock, with our baseline specification generating a mild price puzzle.

There is an important difference in the response of inflation conditional on a positive TFP shock across the two specifications. In our model, the negative response of inflation is relatively short-lived and does not display a hump-shaped pattern. By contrast, the specification with full backward indexation generates a persistent and hump-shaped response of inflation in the wake of a technology improvement. The intuition for this result relates back to the manner in which working capital enters the model. Conditional on a monetary shock, the interest rate falls while factor prices rise, which exerts upward pressure on real marginal cost and hence inflation. A fall in the interest rate counteracts the effect of rising factor prices on marginal cost, which mutes the initial response of inflation to the shock. Conditional on the TFP shock, the interest rate and marginal cost tend to move in the same direction because of the reaction of the interest rate to inflation in the Taylor rule. A TFP shock lowers inflation and hence also the nominal interest rate. The fall in the nominal interest rate works to further decrease marginal cost, which tends to make inflation decrease by more than it would without a working capital channel. Hence, our model with working capital does not generate hump-shaped inflation dynamics conditional on a TFP shock. The version of the model with backward price and wage indexation, in contrast, induces inflation inertia conditional on a TFP shock.

The second, third, and fourth columns in Table 4 show the first order autocorrelation of the first difference of inflation conditional on the monetary policy shock in the two-shock model (second column), the autocorrelation conditional on the productivity shock (third column), and the unconditional autocorrelation of the first difference of inflation when both monetary and TFP shocks are included in the model (fourth column). Consistent with the pattern of impulse responses, in our baseline model there is a positive first order autocorrelation of the first difference of inflation conditional on the monetary policy shock (0.29) and a negative autocorrelation conditional on the monetary policy shock is because $A_t$ effectively enters the aggregate production function twice because of the presence of intermediate goods (which $A_t$ impacts). This scaling ensures that the effect of the productivity shock on TFP (output less share-weighted inputs) is invariant to the value of $\phi$.\footnote{The reason for the scaling of the productivity shock is because $A_t$ effectively enters the aggregate production function twice because of the presence of intermediate goods (which $A_t$ impacts). This scaling ensures that the effect of the productivity shock on TFP (output less share-weighted inputs) is invariant to the value of $\phi$.}
productivity shock ($-0.1$). Unconditionally, our model generates a negative autocorrelation of the first difference of inflation of $-0.09$, relative to $-0.29$ in the data.

The version of the model without working capital and firms networking, but with full backward indexation, in contrast, produces a high positive autocorrelation of the first difference of inflation conditional on the monetary policy shock at 0.73 and a correlation of 0.47 conditional on the TFP shock. Unconditionally, the model with backward indexation produces a first order autocorrelation of the first difference of inflation of 0.48 which is strongly at odds with the data.

Christiano, Eichenbaum and Evans (2005) combine limited borrowing on the wage bill and backward indexation in a model without firms networking. This model generates a high positive autocorrelation of the first difference of inflation conditional on the monetary policy shock at 0.87 and a correlation of 0.51 conditional on the TFP shock. Unconditionally the correlation is 0.52, which is strongly at odds with the data.

Incidentally, our two-shock baseline model continues to imply a mildly procyclical price markup unconditionally. Indeed, we find that the price markup responds positively to a neutral technology improvement in our baseline model. The correlation between the first log differences of the price markup and output is 0.2. In log-levels the correlation in the model is 0.26. When the series are HP-filtered the correlation between the markup and output is 0.1.

### 4 Conclusion

In this paper we have built a medium-scale DSGE model and studied its implications for the dynamics of inflation, output, and the price markup over marginal cost. In addition to many of the usual ingredients of these models, our model includes firms networking in the form of a roundabout production structure and assumes a working capital channel wherein firms have to borrow to finance the cost of all factors of production. The model is able to deliver hump-shaped and inertial inflation dynamics to a monetary policy shock, a large and persistent response of output, and a mild “price puzzle.” It does so with the price markup being procyclical, as recent empirical evidence suggests is the case. While inflation is hump-shaped and inertial conditional on monetary shocks, it is not inertial conditional on a TFP shock, and the unconditional autocorrelation of the first difference of inflation in our model is negative, as it is in the data.

Many papers include backward-indexation or rule of thumb price setters into New Keynesian models to help account for the sluggish behavior of inflation. These features are theoretically unattractive and imply that prices and wages adjust every quarter, which is strongly at odds with available evidence. Our analysis suggests that these features are not necessary to understand the
inertial behavior of inflation. Our model with purely forward-looking price and wage setting does at least well as a model with backward-indexation in accounting for inertial inflation dynamics, and does better along several other dimensions, including the cyclicality of the markup and the unconditional autocorrelation of the first difference of inflation.
References


Figure 1: Output, Inflation, and Price Level Responses

Note: this figure plots the impulse responses of output, inflation, and the price level to a monetary policy shock. The solid lines show the responses in the baseline calibrated model. The dashed lines show responses when there is no firms networking (“No FN”). The dotted lines show responses when there is no extended borrowing (“No EB”). The dashed lines with “+” show responses when there is no firms networking and no extended borrowing, but prices and wages are fully indexed to the lagged inflation rate (“No FN, No EB, Full Backward Indexation”).
Figure 2: Output, Inflation, and Real Marginal Cost

Note: this figure plots the impulse responses of output, inflation, and real marginal cost to a monetary policy shock. The solid lines show the responses in the baseline calibrated model. The dotted lines show responses when there is firms networking and limited borrowing with working capital financing only intermediate goods. ("FN, LBI"). The dashed lines show responses when there is firms networking and limited borrowing with working capital financing only wages. ("FN, LBW").
Figure 3: Price Markup, Wage Markup, and the Labor Wedge

Note: this figure plots the impulse responses of the price markup, the wage markup, and the labor wedge to a monetary policy shock. The solid lines show the responses in the baseline calibrated model. The dotted lines show responses when there is firms networking and limited borrowing with working capital financing only intermediate goods. (“FN, LBI”). The dashed lines show responses when there is firms networking and limited borrowing with working capital financing only wages (“FN, LBW”). The dashed lines with “+” show responses when there is no firms networking and no extended borrowing, but prices and wages are fully indexed to the lagged inflation rate (“No FN, No EB, Full Indexation”).
Figure 4: Extent of Working Capital and the Cyclicality of the Markup

Note: this figure plots the correlation between the price markup and output in first log-differences (solid line), log-levels (dashed line), and HP filtered log-levels (dotted line) as a function of the value of $\psi$, where we assume that $\psi_T = \psi_K = \psi_L = \psi$. In other words, the parameter $\psi$ measures the fraction of factor payments that have to be financed with working capital, assuming that this fraction is the same for all three factors of production. The dashed-dotted line is drawn at zero to facilitate determining the threshold value of $\psi$ capable of delivering a procyclical markup.
Note: this figure plots impulse responses of inflation and the price level to a monetary policy shock for four different parameterizations of the baseline model. The solid lines depict the responses under a baseline parameterization. The dashed line considers the case where wages are stickier, with $\xi_w = 0.75$ instead of 0.66. The dotted line considers the case in which capital utilization is more elastic. For this specification we assume that $\frac{\gamma_2}{\gamma_1} = 0.01$, as in Christiano, Eichenbaum, and Evans (2005).
Figure 6: Inflation Response to Other Shocks

Note: this figure plots impulse responses of inflation to two different shocks in the model – the monetary policy shock and a productivity shock. We do so under three cases: our base model (solid line), the case with no firms networking and no extended borrowing, but where prices and wages are fully indexed to the lagged inflation rate (“No FN, No EB, Full Backward Indexation”) and a version of the model with no firms networking, limited borrowing where only the wage bill must be financed, and full indexation. The process for the productivity shock is described in the text.
Table 1: Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.99</td>
<td>Discount factor</td>
</tr>
<tr>
<td>$b$</td>
<td>0.8</td>
<td>Internal habit formation</td>
</tr>
<tr>
<td>$\eta$</td>
<td>6</td>
<td>Labor disutility</td>
</tr>
<tr>
<td>$\chi$</td>
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<td>Frisch elasticity</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>5</td>
<td>Investment adjustment cost</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.025</td>
<td>Depreciation rate</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>$Z^* = 1$</td>
<td>Utilization adjustment cost linear term</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>0.05</td>
<td>Utilization adjustment cost squared term</td>
</tr>
<tr>
<td>$\epsilon_p$</td>
<td>0.66</td>
<td>Calvo price</td>
</tr>
<tr>
<td>$\epsilon_w$</td>
<td>0.66</td>
<td>Calvo wage</td>
</tr>
<tr>
<td>$\zeta_p$</td>
<td>0</td>
<td>Price indexation</td>
</tr>
<tr>
<td>$\zeta_w$</td>
<td>0</td>
<td>Wage indexation</td>
</tr>
<tr>
<td>$\theta$</td>
<td>6</td>
<td>Elasticity of substitution: goods</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>6</td>
<td>Elasticity of substitution: labor</td>
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<tr>
<td>$\phi$</td>
<td>0.624</td>
<td>Intermediate share</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1/3</td>
<td>Capital share</td>
</tr>
<tr>
<td>$F$</td>
<td>$\Pi^* = 0$</td>
<td>Fixed cost</td>
</tr>
<tr>
<td>$\psi_L$</td>
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<td>Fraction of labor financed</td>
</tr>
<tr>
<td>$\psi_K$</td>
<td>1</td>
<td>Fraction of capital financed</td>
</tr>
<tr>
<td>$\psi_T$</td>
<td>1</td>
<td>Fraction of intermediates financed</td>
</tr>
<tr>
<td>$\rho_t$</td>
<td>0.8</td>
<td>Taylor rule smoothing</td>
</tr>
<tr>
<td>$\alpha_\pi$</td>
<td>1.5</td>
<td>Taylor rule inflation</td>
</tr>
<tr>
<td>$\alpha_y$</td>
<td>0.2</td>
<td>Taylor rule output growth</td>
</tr>
<tr>
<td>$\pi^*$</td>
<td>0</td>
<td>Trend inflation</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.002</td>
<td>SD Taylor rule shock</td>
</tr>
</tbody>
</table>

Note: this table shows the values of the parameters used in quantitative analysis of the model. A description of each parameter is provided in the right column. The parameter on the linear term in the utilization adjustment cost function, $\gamma_1$, is chosen to be consistent with a steady state normalization of utilization to 1. Given other parameters this implies a value $\gamma_1 = 0.0351$. The fixed cost of production, $F$, is chosen so that profits equal zero in the non-stochastic steady state. Given other parameters, this implies a value of $F = 0.0191$.

Table 2: Output and Inflation Dynamics

<table>
<thead>
<tr>
<th>Inflation autocorrelation</th>
<th>Output half-life</th>
<th>Lag 1</th>
<th>Lag 2</th>
<th>Lag 3</th>
<th>Lag 4</th>
<th>Lag 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base model</td>
<td>14</td>
<td>0.9248</td>
<td>0.8054</td>
<td>0.6682</td>
<td>0.5307</td>
<td>0.4032</td>
</tr>
<tr>
<td>No EB, no FN</td>
<td>12</td>
<td>0.8331</td>
<td>0.6659</td>
<td>0.5153</td>
<td>0.3877</td>
<td>0.2842</td>
</tr>
<tr>
<td>No EB, no FN, full indexation</td>
<td>6</td>
<td>0.9507</td>
<td>0.8293</td>
<td>0.6662</td>
<td>0.4893</td>
<td>0.3203</td>
</tr>
</tbody>
</table>

Note: this table shows some statistics from different versions of the model. The column labeled “Output half-life” shows the half-life of output in response to a monetary policy shock, which we define as the number of quarters (rounded to the nearest integer) after which the impulse response of output is one-half its impact response. The remaining columns show autocorrelations of inflation at different lags. The row labeled “No EB, no FN” refers to a version of the model with no extended borrowing and no firms networking. The remaining row augments this case to consider full indexation of prices and wages to lagged inflation.
Table 3: Cyclicality of the Price Markup, Wage Markup and the Labor Wedge

(a) Price Markup

<table>
<thead>
<tr>
<th></th>
<th>First Differences</th>
<th>Log-Levels</th>
<th>HP Filtered Log-Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model</td>
<td>0.4226</td>
<td>0.0877</td>
<td>0.1589</td>
</tr>
<tr>
<td>LBI, FN</td>
<td>0.3162</td>
<td>-0.2271</td>
<td>-0.0583</td>
</tr>
<tr>
<td>LBW, FN</td>
<td>-0.0418</td>
<td>-0.8117</td>
<td>-0.6221</td>
</tr>
<tr>
<td>No EB, no FN</td>
<td>-0.9793</td>
<td>-0.9653</td>
<td>-0.9700</td>
</tr>
<tr>
<td>No EB, no FN, full Indexation</td>
<td>-0.9883</td>
<td>-0.9815</td>
<td>-0.9835</td>
</tr>
<tr>
<td>LBW, no FN, full Indexation</td>
<td>0.1068</td>
<td>-0.3170</td>
<td>-0.3109</td>
</tr>
<tr>
<td>No EB, FN</td>
<td>-0.9951</td>
<td>-0.9844</td>
<td>-0.9927</td>
</tr>
<tr>
<td>EB, no FN</td>
<td>0.2362</td>
<td>-0.4789</td>
<td>-0.2990</td>
</tr>
<tr>
<td>Nekarda and Ramey (2013)</td>
<td>0.4950</td>
<td>n/a</td>
<td>0.3250</td>
</tr>
</tbody>
</table>

(b) Wage Markup

<table>
<thead>
<tr>
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<th>First Differences</th>
<th>Log-Levels</th>
<th>HP Filtered Log-Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model</td>
<td>-0.6458</td>
<td>-0.7622</td>
<td>-0.6655</td>
</tr>
<tr>
<td>LBI, FN</td>
<td>-0.6369</td>
<td>-0.7759</td>
<td>-0.6708</td>
</tr>
<tr>
<td>LBW, FN</td>
<td>-0.5974</td>
<td>-0.7564</td>
<td>-0.6365</td>
</tr>
<tr>
<td>No EB, no FN</td>
<td>-0.7299</td>
<td>-0.8456</td>
<td>-0.7640</td>
</tr>
<tr>
<td>No EB, no FN, full Indexation</td>
<td>-0.7805</td>
<td>-0.8677</td>
<td>-0.8368</td>
</tr>
<tr>
<td>LBW, no FN, full Indexation</td>
<td>-0.7000</td>
<td>-0.8586</td>
<td>-0.8190</td>
</tr>
<tr>
<td>No EB, FN</td>
<td>-0.6651</td>
<td>-0.7855</td>
<td>-0.6800</td>
</tr>
<tr>
<td>EB, no FN</td>
<td>-0.7317</td>
<td>-0.8458</td>
<td>-0.7705</td>
</tr>
</tbody>
</table>

(c) Labor Wedge

<table>
<thead>
<tr>
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<th>First Differences</th>
<th>Log-Levels</th>
<th>HP Filtered Log-Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model</td>
<td>-0.6722</td>
<td>-0.7956</td>
<td>-0.7057</td>
</tr>
<tr>
<td>LBI, FN</td>
<td>-0.6733</td>
<td>-0.8226</td>
<td>-0.7287</td>
</tr>
<tr>
<td>LBW, FN</td>
<td>-0.6053</td>
<td>-0.7644</td>
<td>-0.6466</td>
</tr>
<tr>
<td>No EB, no FN</td>
<td>-0.7509</td>
<td>-0.8623</td>
<td>-0.7894</td>
</tr>
<tr>
<td>No EB, no FN, full Indexation</td>
<td>-0.7978</td>
<td>-0.8814</td>
<td>-0.8537</td>
</tr>
<tr>
<td>LBW, no FN, full Indexation</td>
<td>-0.7326</td>
<td>-0.8795</td>
<td>-0.8454</td>
</tr>
<tr>
<td>No EB, FN</td>
<td>-0.6796</td>
<td>-0.8052</td>
<td>-0.7038</td>
</tr>
<tr>
<td>EB, no FN</td>
<td>-0.7640</td>
<td>-0.8665</td>
<td>-0.8045</td>
</tr>
</tbody>
</table>

Note: this table shows statistics for the cyclicality of the price markup, wage markup and labor wedge (correlation with output) for different versions of the model and for different filtering methods. FN: firms networking; EB: extended borrowing with working capital financing working capital financing all inputs; LBI: limited borrowing working capital financing only intermediate goods; LBW: limited borrowing with working capital financing only wages.
Table 4: Autocorrelation of First Difference of Inflation

<table>
<thead>
<tr>
<th></th>
<th>Monetary Shock Only</th>
<th>Monetary and Productivity Shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monetary</td>
<td>Monetary</td>
</tr>
<tr>
<td>Base model</td>
<td>0.2944</td>
<td>0.2944</td>
</tr>
<tr>
<td>No EB, no FN, full indexation</td>
<td>0.7311</td>
<td>0.7311</td>
</tr>
<tr>
<td>LBW, no FN, full indexation</td>
<td>0.8678</td>
<td>0.8678</td>
</tr>
<tr>
<td>Data, 1960-2015</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: this table presents first order autocorrelations of the first difference of inflation in different versions of the model as well as in the data. We do so conditional on the two different shocks described in Subsection 3.4, as well as unconditionally when two shocks are included in the model. The parameterization of the additional shock processes is as described in the text. “Base Model” refers to our baseline model. “No EB, no FN, full indexation” omits working capital and roundabout production from the model, but assumes full backward indexation of both prices and wages to lagged inflation. “LBW, No FN, full indexation” is essentially the Christiano, Eichenbaum and Evans (2005) specification. The rows labeled “Data” compute the first order autocorrelation of the first difference of inflation for the postwar period. We measure inflation as the log first difference of the GDP Implicit Price Deflator.
A Full Set of Equilibrium Conditions

This appendix lists the full set of equilibrium conditions:

\[ \lambda_t^r = \frac{1}{C_t - bC_{t-1}} - E_t \frac{\beta b}{C_{t+1} - bC_t} \]  
(A1)

\[ r_t^k = \gamma_1 + \gamma_2 (Z_t - 1) \]  
(A2)

\[ \lambda_t^r = \mu_t \left( 1 - \frac{k}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \kappa \left( \frac{I_t}{I_{t-1}} - 1 \right) \right) + \beta E_t \mu_{t+1} \kappa \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 \]  
(A3)

\[ \mu_t = \beta E_t \lambda_{t+1}^r \left( r_{t+1}^k Z_{t+1} - \left( \gamma_1 (Z_{t+1} - 1) + \gamma_2 (Z_{t+1} - 1)^2 \right) \right) + \beta (1 - \delta) E_t \mu_{t+1} \]  
(A4)

\[ \lambda_t^r = \beta E_t (1 + i_t) \pi_{t+1}^{-1} \lambda_{t+1}^r \]  
(A5)

\[ w_t^* = \frac{\sigma}{\sigma - 1} \frac{f_{1,t}}{f_{2,t}} \]  
(A6)

\[ f_{1,t} = \eta \left( \frac{w_t}{w_t^*} \right)^{(1+\chi)} L_t^{1+\chi} + \beta \xi_w \pi_t^{-\xi_w (1+\chi)} E_t (\pi_{t+1})^{\sigma \chi} \left( \frac{w_{t+1}}{w_t^*} \right)^{(1+\chi)} f_{1,t+1} \]  
(A7)

\[ f_{2,t} = \lambda_t^r \left( \frac{w_t}{w_t^*} \right)^\sigma L_t + \beta \xi_w \pi_t^{\xi_w (1-\sigma)} E_t (\pi_{t+1})^{\sigma - 1} \left( \frac{w_{t+1}}{w_t^*} \right)^\sigma f_{2,t+1} \]  
(A8)

\[ \tilde{K}_t = \alpha (1 - \phi) mc_t r_t^{1/2} (s_t X_t + F) \]  
(A9)

\[ L_t = (1 - \alpha) (1 - \phi) mc_t (1 + i_t) \pi_t w_t (s_t X_t + F) \]  
(A10)

\[ \Gamma_t = \phi mc_t (s_t X_t + F) \]  
(A11)

\[ p_t^* = \frac{\theta}{\theta - 1} \frac{x_t^1}{x_t^2} \]  
(A12)

\[ x_t^1 = \lambda_t^r mc_t X_t + \xi_p \beta \pi_t^{-\xi_p \theta} \pi_{t+1}^{\xi_p \theta} x_{t+1}^1 \]  
(A13)

\[ x_t^2 = \lambda_t^r X_t + \xi_p \beta \pi_t^{-\xi_p (1-\theta)} \pi_{t+1}^{\xi_p (1-\theta)} x_{t+1}^2 \]  
(A14)

\[ 1 = \xi_p \pi_t^{\xi_p (1-\theta)} \pi_{t-1}^{1-\xi_p (1-\theta)} + (1 - \xi_p) (p_t^*)^{1-\theta} \]  
(A15)

\[ w_t^{1-\sigma} = \xi_w \left( \frac{w_{t-1}}{\pi_t} \right)^{\xi_w (1-\sigma)} + (1 - \xi_w) (w_t^*)^{1-\sigma} \]  
(A16)

\[ Y_t = X_t - \Gamma_t \]  
(A17)

\[ s_t X_t = \Gamma_t \tilde{K} (1 - \phi) L_t^{1 - \alpha (1 - \phi)} - F \]  
(A18)

\[ Y_t = C_t + I_t + \left( \gamma_1 (Z_t - 1) + \gamma_2 (Z_t - 1)^2 \right) K_t \]  
(A19)

\[ K_{t+1} = \left( 1 - \frac{\kappa}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t + (1 - \delta) K_t \]  
(A20)
\[
\frac{1 + i_t}{1 + \bar{i}} = \left( \frac{1 + i_{t-1}}{1 + \bar{i}} \right)^{\rho_i} \left[ \left( \frac{\pi_t}{\bar{\pi}} \right)^{\alpha_p} \left( \frac{Y_t}{Y_{t-1}} \right)^{\alpha_y} \right]^{1 - \rho_i} \hat{\epsilon}_t
\]  
(A21)

\[
\tilde{K}_t = Z_t K_t
\]  
(A22)

\[
s_t = (1 - \xi_p) p_t^{s-\theta} + \xi_p \pi_{t-1}^{-\zeta_p} \pi_t^{\theta} s_{t-1}
\]  
(A23)

Equation (A1) defines the real multiplier on the flow budget constraint. (A2) is the optimality condition for capital utilization. (A3) and (A3) are the optimality conditions for the household choice of investment and next period’s stock of capital, respectively. The Euler equation for bonds is given by (A5). (A6)-(A8) describe optimal wage setting for households given the opportunity to adjust their wages. Optimal factor demands are given by equations (A9)-(A11). Optimal price setting for firms given the opportunity to change their price is described by equations (A12)-(A14). The evolutions of aggregate inflation and the aggregate real wage index are given by (A15) and (A16), respectively. Net output is gross output minus intermediates, as given by (A17). The aggregate production function is (A18). The aggregate resource constraint is (A19), and the law of motion for physical capital is given by (A20). The Taylor rule for monetary policy is (A21). Capital services are defined as the product of utilization and physical capital, as in (A22). The law of motion for price dispersion is (A23).