Firm-Specific Capital, Nominal Rigidities, and the Taylor Principle*

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Abstract

In the presence of firm-specific capital the Taylor principle can generate multiple equilibria. Sveen and Weinke (2005) obtain that result in the context of a Calvo-style sticky price model. One potential criticism is that the price stickiness which is needed for our theoretical result to be relevant from a practical point of view is somewhat to the high part of available empirical estimates. In the present paper we show that if nominal wages are not fully flexible (which is an uncontroversial empirical fact) then the Taylor principle fails already for some minor degree of price stickiness. We use our model to explain the consequences of both nominal rigidities for the desirability of alternative interest rate rules.

Keywords: Nominal Rigidities, Aggregate Investment, Monetary Policy.

JEL Classification: E22, E31

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1 Introduction

According to the conventional wisdom a central bank can avoid becoming a source of unnecessary macroeconomic fluctuations by simply following the Taylor principle. The latter prescribes to adjust the nominal interest rate by more than one-for-one in response to changes in inflation. Indeed, many New-Keynesian (NK) models imply that the Taylor principle is a sufficient condition for determinacy, i.e. local uniqueness of rational expectations equilibrium (REE), a property that is, in turn, often used to explain macroeconomic stability or lack thereof.¹

Sveen and Weinke (2005) show, however, that the Taylor principle can easily fail to guarantee determinacy if it is taken into account that firms do not only post prices but also make investment decisions.² Interestingly, we find that the empirically plausible design of monetary policy in the US since the early eighties³ can explain the isochronal stabilization of macroeconomic outcomes, whereas the Taylor principle in itself cannot.

One potential criticism is as follows. The Taylor principle remains a sufficient condition for determinacy in the context of our 2005 model if prices are flexible enough. Indeed, the indeterminacy problem we uncover in that paper only exists if the average expected lifetime of a price is at least three quarters. That is not implausible.⁴ If firms were to change their prices, however, about every 5.5 months, as Bils and Klenow (2004) report, then the Taylor principle would be sufficient for determinacy. The case for combining that principle with some responsiveness of the nominal interest rate to a measure of real economic activity and/or some interest rate smoothing, the main conclusion our 2005 paper, would then be less convincing.

¹See, e.g., Taylor (1999a), Clarida et al. (2000) and Woodford (2001).
²See, e.g., Edge and Rudd (2002), Reisland (2003), and Galí et al. (2004) for alternative assumptions under which the Taylor principle fails to guarantee determinacy. Moreover Benhabib and Eusepi (2005) discuss the possibility of global instability which might occur even if REE is locally unique.
³See, e.g., Woodford (2003, Ch. 1) for an overview of empirical studies on interest rate rules.
The first result in the present paper addresses that criticism. We find that the presence of sticky nominal wages, an uncontroversial empirical fact, implies that our earlier conclusion remains valid even in the event that prices are as flexible as Bils and Klenow (2004) suggest.

Next we consider monetary policy rules prescribing that the nominal interest rate is adjusted in response to changes in a weighted average of price and wage inflation. Schmitt-Grohé and Uribe (2005) find in the context of a NK model featuring a rich variety of nominal and real rigidities as well as a rental market for capital that the weights attached to price and to wage inflation do not matter for indeterminacy as long as the nominal interest rate is adjusted by more than one-for-one in response to changes in weighted average inflation. We confirm their finding for the indeterminacy region for which the critical value of the weighted average inflation coefficient is exactly one. On the other hand, for the second region which starts at values for that coefficient which are larger than one (and which is generally turned off by the rental market assumption), we find that the weights attached to price and to wage inflation matter a lot: the size of that region decreases substantially if the weight on wage inflation is increased.

Finally, compared with an economic environment where only prices are sticky we find that responding to a measure of real economic activity becomes more effective in reducing the indeterminacy problem, whereas the opposite is true for interest rate smoothing. We confirm, however, our earlier result that empirically plausible interest rate rules guarantee macroeconomic stability.

The remainder of the paper is organized as follows. Section 2 outlines the model structure. In Section 3 we consider the resulting linearized equilibrium conditions. Our results are presented in Section 4 and Section 5 concludes.
2 The Model

We use a NK model with complete markets. Sunspot shocks are assumed to be the only source of aggregate uncertainty. There is a continuum of households and a continuum of firms. Each household (firm) is the monopolistically competitive supplier of a differentiated type of labor (type of good) and we assume sticky wages (sticky prices) à la Calvo (1983), i.e. each household (firm) gets to reoptimize its wage (price) with a constant and exogenous probability. Capital accumulation is assumed to take place at the firm level and the additional capital resulting from an investment decision becomes productive with a one period delay. Moreover, we follow Woodford (2003, Ch. 5, 2005) in assuming a convex capital adjustment cost at the firm level. Since the details of the model have been discussed elsewhere\(^5\) we turn directly to the resulting linearized equilibrium conditions.

3 Some Linearized Equilibrium Conditions

We restrict attention to a linear approximation around a zero inflation steady state. In what follows variables are expressed in terms of log deviations from their steady state values except for the nominal interest rate, \(i_t\), and inflation, \(\pi_t\), which denote the level of the respective variable. The consumption Euler equation reads:

\[
c_t = E_t c_{t+1} - \frac{1}{\sigma} (i_t - E_t \pi_{t+1} - \rho),\tag{1}
\]

where \(c_t\) denotes aggregate consumption and \(E_t\) is the expectational operator conditional on information available through time \(t\). Moreover, parameter \(\rho\) is the time discount rate and parameter \(\sigma\) measures the household’s relative risk aversion.

The law of motion of capital is obtained from averaging and aggregating optimal

\(^5\)See, Sveen and Weinke (2005), Woodford (2005), and Erceg et al. (2000).
investment decisions on the part of firms. This implies:

\[ \Delta k_{t+1} = \beta E_t \Delta k_{t+2} + \frac{1}{\epsilon \psi} [(1 - \beta(1 - \delta)) E_t m s_{t+1} - (i_t - E_t \pi_{t+1} - \rho)]; \quad (2) \]

where aggregate capital is denoted \( k_t \) and \( m s_t \equiv r w_t - (k_t - n_t) \) measures the average real marginal return to capital. In the latter definition we have used the notation \( r w_t \) for the average real wage and \( n_t \) for aggregate labor. The average real marginal return to capital is measured in terms of marginal savings in labor costs since firms are demand-constrained in our model. Moreover, parameter \( \beta \) denotes the subjective discount factor, while parameter \( \delta \) is the depreciation rate of capital. Finally, parameter \( \epsilon \psi \) measures the capital adjustment cost at the firm level, as in Woodford (2003, Ch. 5, 2005).

Up to the first order, aggregate production is pinned down by aggregate labor and capital:

\[ y_t = \alpha k_t + (1 - \alpha) n_t, \quad (3) \]

where parameter \( \alpha \) denotes the capital share. The wage inflation equation results from averaging and aggregating optimal wage setting decisions on the part of households, as discussed in Erceg et al. (2000). It takes the following simple form:

\[ \omega_t = \beta E_t \omega_{t+1} + \lambda_\omega \ (m r s_t - r w_t), \quad (4) \]

where \( \omega_t \) denotes wage inflation while \( m r s_t \equiv \sigma c_t + \eta n_t \) measures the average marginal rate of substitution of consumption for leisure. Parameter \( \eta \) indicates the inverse of the (aggregate) Frisch labor supply elasticity. Finally, we have used the definition \( \lambda_\omega \equiv \frac{(1 - \beta \theta_w)(1 - \theta_w)}{\theta_w} \frac{1}{1 + \epsilon_N} \). In the latter expression parameter \( \theta_w \) denotes the probability that a household is not allowed to reoptimize its nominal wage in any given period, while parameter \( \epsilon_N \) measures the elasticity of substitution between different types of labor.
The price inflation equation takes the standard form:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda m c_t, \quad (5)$$

where $m c_t \equiv rw_t - (y_t - n_t)$ denotes the average real marginal cost. We have also used the definition $\lambda \equiv \frac{(1-\beta\theta)(1-\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha \xi} 1$ where parameter $\theta$ gives the probability that a firm does not get to reoptimize its price in any given period, while parameter $\varepsilon$ denotes the elasticity of substitution between the differentiated goods. Finally, parameter $\xi$ is a function of the model’s structural parameters which is computed numerically using the method developed in Woodford (2005).6

The goods market clearing condition reads:

$$y_t = \zeta c_t + \frac{1-\zeta}{\delta} [k_{t+1} - (1-\delta) k_t], \quad (6)$$

where $\zeta \equiv 1 - \frac{\delta \alpha}{\mu (\rho+\delta)}$ denotes the steady state consumption to output ratio. In the latter definition we have denoted the frictionless desired markup by $\mu \equiv \frac{\varepsilon}{\varepsilon-1}$. Next we will use the model developed so far to analyze the desirability of alternative interest rate rules.

4 Results

4.1 Baseline Parameter Values

Let us start by mentioning the values which we assign to the model parameters in most of the quantitative analysis that we are going to conduct. We set the capital share $\alpha = 0.36$. Our choice for the risk aversion parameter $\sigma$ is 2. The elasticity of substitution between goods, $\varepsilon$, is set to 11. The rate of capital depreciation, $\delta$, is assumed to be equal to 0.025 and we set $\epsilon_\psi = 3$. These parameter values are justified in Sveen and Weinke (2005), Erceg et al. (2000) and the references therein.

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6Sveen and Weinke (2004) observe that the loss in accuracy is negligible if $\xi$ is set to one.
We set the elasticity of substitution between different types of labor, $\varepsilon_N$, equal to 6, a conventional value in the empirically plausible range range between 4, as in Erceg et al. (2000), and 21 which is the value assumed in Altig et al. (2005). Finally, our baseline value for the Calvo wage stickiness parameter, $\theta_w$, is 0.75 which implies an average expected duration of a wage contract of one year. That is consistent with the empirical evidence in Taylor (1999b), Smets and Wouters (2003), Christiano et al. (2005), and Levin et al. (2005). In the quantitative exercises below we assign values from 0.35 to 0.90 to the Calvo price stickiness parameter, $\theta$, which covers the range of values for which some empirical evidence can be found.

4.2 Nominal Rigidities, Firm-Specific Capital and the Taylor Principle

We consider the following simple rule for monetary policy:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \{ \rho + \tau_\pi [(1 - \tau_\omega) \pi_t + \tau_\omega \omega_t] + \tau_y y_t \},$$

(7)

where parameter $\rho_i$ measures the degree of interest rate smoothing, $\tau_\pi$ denotes the responsiveness of the nominal interest rate to a weighted average of price and wage inflation, while $\tau_\omega$ indicates the relative weight attached to wage inflation. Finally, $\tau_y$ denotes the responsiveness to the output gap, i.e. the difference between output and its natural level. Specifically, we follow Woodford (2003, Ch. 5) in defining the latter as the level of output that would obtain if nominal rigidities were currently absent and expected to be absent in the future but taking as given the current capital stock which results from past investment choices that have been made in an economic environment with the nominal rigidities being present.\(^7\)

\(^7\)An alternative definition of natural output has been proposed by Neiss and Nelson (2003). Their definition assumes that prices are not only currently flexible and expected to be flexible in the future but that they had been also flexible in the past. Recently, Sveen and Weinke (2006) have shown, however, that the welfare properties of interest rate rules do not appear to hinge upon the particular definition of natural output that is used to construct the output gap.
First, we consider a simple interest rate rule prescribing that the nominal interest rate is set as a function of only inflation, i.e. \( \rho_i = \tau_\omega = \tau_y = 0 \). The results are shown in figure 1.

![Figure 1: Indeterminacy with wage and price stickiness and firm-specific capital.](image)

If all the remaining parameter values are held constant at their baseline values then the Taylor principle fails to guarantee determinacy if firms adjust prices at least every 1.65 quarters on average (\( \theta = 0.395 \)).

Let us now develop our intuition. An increase in investment demand has counteracting effects on the determination of the real marginal cost, as analyzed in Sveen and Weinke (2005). First, the associated additional production tends to increase the marginal cost. The reason is an increase in the real wage as well as a decrease in labor productivity (since firms’ technology features short-run decreasing returns to scale). Second, the resulting additional capital increases future labor productivity.
and therefore decreases the marginal cost. Inflation inherits the dynamic pattern of the marginal cost and if the central bank follows the Taylor principle then the same is true for short term real interest rates. It is therefore possible that the second effect, i.e. the future reduction in real interest rates, dominates the determination of the long-run real interest rate in which case an investment boom could potentially become self-fulfilling. Whether or not that happens depends on the extent to which prices and wages are sticky. First, if prices are set in a forward-looking manner then the future expected reduction in marginal cost associated with an investment boom affects current price setting decisions. As a result the impact response of inflation and hence (under the Taylor principle) of the short term real rate is small enough that the long term real rate drops. Second, the presence of sticky nominal wages combined with sticky prices tends to dampen the increase in the real wage when an investment boom hits the economy. The second effect in the determination of the long-run real interest rate, i.e. the one stemming from the future increase in labor productivity associated with an investment boom, becomes then dominant. This explains why the degree of price stickiness which causes the Taylor principle to fail in the context of a model featuring firm-specific investment is dramatically reduced in the presence of sticky wages.

4.3 A Rationale for Reacting to Wage Inflation

Next we analyze the determinacy properties of interest rate rules prescribing that the nominal rate is set as a function of price inflation and wage inflation. Schmitt-Grohé and Uribe (2005) find that rules of this kind guarantee determinacy if the sum of the coefficients measuring the responsiveness of the nominal rate to price and to wage inflation is larger than one. In our interest rate rule this corresponds to

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8The importance of that mechanism is obscured if a rental market for capital is assumed, as discussed in Sveen and Weinke (2005). Even in that case forward-looking interest rate rules are problematic, as analyzed in Carlstrom and Fuerst (2005).

9Ball and Romer (1990), Kiley (1997) and Farmer (2000) provide early discussions of the role of real rigidities for equilibrium determination. This concept applies to any model feature that limits the size of adjustment of relative prices to changes in aggregate demand.
setting $\tau_{\pi} > 1$. They obtain that result in the context of a medium scale NK model featuring a rich variety of nominal and real rigidities as well as a rental market for capital. As shown in figure 2 we confirm their result as far as the standard indeterminacy region (i.e. the one for which the critical value is exactly one) is concerned. However, as far as the second indeterminacy region is concerned, i.e. the one which corresponds to values of the responsiveness parameter that are larger than one, we reach a different conclusion. For any given value of the price stickiness parameter we find that the indeterminacy region becomes smaller if the weight on wage inflation increases.

![Figure 2: Indeterminacy when reacting to nominal wage inflation.](image)

The economic reason why the relative weight attached to price and to wage inflation in the interest rate rule matters for the size of the indeterminacy region is as follows. Assume that the coefficients measuring the responsiveness of the nominal
interest rate to the weighted average of wage and price inflation is larger than one. If
the weight on wage inflation is large then the future reduction in labor productivity
associated with an investment boom does not directly translate into a reduction of
future real interest rates. This reduces the possibility of indeterminacy.

4.4 The Case for Taylor-Type Rules

In our 2005 paper we show how the indeterminacy problem can be solved if the
central bank combines the Taylor principle with some responsiveness of the nominal
interest rate to a measure of real economic activity and/or some interest rate
smoothing. Here we ask to what extent that conclusion is changed in the presence
of two nominal rigidities. The results are shown in figure 3.

Figure 3: Indeterminacy with a Taylor type rule.
Compared with an economic environment where only prices are sticky we find that responding to a measure of real economic activity becomes more effective in reducing the size of the indeterminacy region, whereas the opposite is true for interest rate smoothing. The intuition relies again on the fact that sticky wages when combined with sticky prices imply a slow adjustment of the real wage, hence of the marginal cost and ultimately of inflation in response to any change in aggregate demand. That property implies the following. The change in real economic activity associated with an investment boom becomes more pronounced which increases the effectiveness of an interest rate rule prescribing to react to that. Moreover, as we found in our 2005 paper, interest rate smoothing enhances macroeconomic stability because the initial increase in inflation after an investment boom will keep being relevant for the determination of future real rates. With wage stickiness inflation reacts initially by less and therefore this channel becomes less important. Despite these differences in the economic mechanism we confirm, however, our earlier result that empirically plausible interest rate rules guarantee macroeconomic stability.

5 Conclusion

We show that the practical relevance of the indeterminacy problem discussed in Sveen and Weinke (2005) is dramatically increased if sticky nominal wages are added (realistically) to the analysis. Specifically, the Taylor principle fails to guarantee determinacy in our NK model with firm-specific capital if prices are as flexible as the lowest available empirical estimates suggest. That strengthens the case for some responsiveness of the nominal interest rate to a measure of real economic activity and/or some interest rate smoothing on stability grounds, as we show. This conclusion is also supported by Hornstein and Wolman (2005) who show that the indeterminacy problem implied by the Taylor principle becomes more severe in the presence of non-zero average inflation.
6 References


