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by

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

Tommy Sveen† Lutz Weinke‡

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Abstract

In the presence of firm-specific capital the Taylor principle can *generate* multiple equilibria. Sveen and Weinke (2005b) 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 (2005b) 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] Specifically, we show that there exists an indeterminacy region which obtains for policies that respect the Taylor principle (in addition to the usual region which corresponds to interest rate rules that are inconsistent with that principle). Interestingly, we find that the empirically plausible design of monetary policy in the US since the early eighties[3] 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 2005b 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] but if firms were to change their prices 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

[1] See, e.g., Taylor (1999a), Clarida et al. (2000) and Woodford (2001).

[2] Earlier contributions which analyze some problems with the Taylor principle include Edge and Rudd (2002), Røisland (2003), and Galí et al. (2004). Moreover Benhabib and Eusepi (2005) discuss the possibility of global instability which might occur even if REE is locally unique.

[3] See, e.g., Woodford (2003, Ch. 1) for an overview of empirical studies on interest rate rules.

[4] See, e.g., the empirical evidence reported in Taylor (1999b), Aucremanne and Dhyne (2004) and Baudry and Le Bihan (2004).

nominal interest rate to a measure of real economic activity and/or some interest rate smoothing, the main conclusion our 2005b paper, would then be less convincing. 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.[5]

In a nutshell the intuition is as follows. First, capital accumulation *per se* opens up the possibility that the Taylor principle fails. If firms increase their investment without any change in the economy's fundamentals justifying that then the real marginal cost tends to increase on impact (investment goods need to be produced), whereas it tends to decrease by the time when the additional capital resulting from the investment activity becomes productive. Inflation inherits the dynamic pattern of the marginal cost and to the extent that the central bank follows the Taylor principle the same is true for short term real rates. Thus the long term real rate could potentially drop in the event of an investment boom and the latter could therefore be rationalized ex post. Whether that happens or not depends on the size of the nominal rigidities. We show that for a conventional specification of nominal wage stickiness the Taylor principle fails to guarantee determinacy even if prices are as flexible as Bils and Klenow (2004) report. The reason is that in the presence of both nominal rigidities the *real* wage adjusts only slowly to any change in aggregate demand.[6] 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.

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.

[5] Another empirically plausible feature that enlargens the set of parameter values for which indeterminacy obtains is non-zero average inflation, as Hornstein and Wolman (2005) have shown in the context of a Taylor-type sticky price model with firm-specific capital.

[6] Ball 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.

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. Our intuition is that the future increase in labor productivity resulting from an investment boom does not directly translate into a decrease of future real interest rates if the nominal interest rate responds to wage inflation as opposed to price inflation.

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. The intuition relies again on the fact that sticky wages when combined with sticky prices imply a slow adjustment of the marginal cost and hence 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, the effectiveness of reacting to past interest rates is reduced since the initial increase is smaller. Despite these differences in the economic mechanism we confirm our earlier conclusion 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[7] 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, π_t, which denote the level of the respective variable. The consumption Euler equation reads:

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

where c_t denotes aggregate consumption and E_t is the expectational operator conditional on information available trough time t. Moreover, parameter ρ is the time discount rate and parameter σ measures the household's relative risk aversion.

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

[7] See, Sveen and Weinke (2005b), Woodford (2005), and Erceg et al. (2000).

investment decisions on the part of firms. This implies:

$$\Delta k_{t+1} = \beta E_t \Delta k_{t+2} + \frac{1}{\epsilon_\psi} \left[\left(1 - \beta(1-\delta)\right) E_t ms_{t+1} - \left(i_t - E_t \pi_{t+1} - \rho\right) \right], \tag{2}$$

where aggregate capital is denoted k_t and $ms_t \equiv rw_t - (k_t - n_t)$ measures the average real marginal return to capital. In the latter definition we have used the notation rw_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 β denotes the subjective discount factor, while parameter δ is the depreciation rate of capital. Finally, parameter ϵ_ψ measures the capital adjustment cost at the firm level, as in Woodford (2003, Ch. 5, 2005).[8]

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

$$y_t = \alpha k_t + (1-\alpha)\, n_t, \tag{3}$$

where parameter α 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:

$$\omega_t = \beta E_t \omega_{t+1} + \lambda_\omega \ \left(mrs_t - rw_t\right), \tag{4}$$

where ω_t denotes wage inflation while $mrs_t \equiv \sigma c_t + \eta n_t$ measures the average marginal rate of substitution of consumption for leisure. Parameter η indicates the inverse of the (aggregate) Frisch labor supply elasticity. Finally, we have used the definition $\lambda_\omega \equiv \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w} \frac{1}{1+\eta\varepsilon_N}$. In the latter expression parameter θ_w denotes the probability that a household is not allowed to reoptimize its nominal wage in

[8] In related work Sveen and Weinke (2005a) have shown that the linearized equlibrium conditions associated with a NK model featuring lumpy firm-level investment are identical to the ones implied by the assumption of a convex capital adjustment cost at the firm level. Our results in the present paper do therefore not appear to hinge on the convex capital adjustment cost assumption.

any given period, while parameter ε_N measures the elasticity of substitution between different types of labor.

The price inflation equation takes the standard form:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \; mc_t, \tag{5}$$

where $mc_t \equiv rw_t - (y_t - n_t)$ denotes the average real marginal cost. Parameter λ is a function of the model's structural parameters which is computed numerically using the method developed in Woodford (2005). It is useful to note that the loss in accuracy is negligible if λ is approximated by $\frac{(1-\beta\theta)(1-\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha\varepsilon}$, where parameter θ gives the probability that a firm does not get to reoptimize its price in any given period, while parameter ε denotes the elasticity of substitution between the differentiated goods. The assumption of endogenous firm-specific capital does therefore *not* imply any important change it the dynamic relationship between inflation and the average real marginal cost with respect to the one that obtains in a model featuring a constant capital stock at the firm level. That result has been obtained in Sveen and Weinke (2004).[9] In the present paper we use this observation to develop an intuition behind our results. We will come back to that point.

The goods market clearing condition reads:

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

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.

[9] Our 2004 solution to the problem of solving for the equilibrium dynamics in the presence of Calvo pricing and endogenous firm-specific capital was obtained by using a method which is computationally less efficient than the one presented in Woodford (2005). Both techniques rely, however, on similar observations regarding the model structure, as noted by Hornstein and Wolman (2005).

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 σ is 2. The elasticity of substitution between goods, ε, is set to 11. The rate of capital depreciation, δ, is assumed to be equal to 0.025 and we set $\epsilon_{\psi} = 3$. These parameter values are justified in Sveen and Weinke (2005b), Erceg et al. (2000) and the references therein. We set the elasticity of substitution between different types of labor, ε_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, θ_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, θ, 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:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \left\{ \rho + \tau_\pi \left[(1 - \tau_\omega) \pi_t + \tau_\omega \omega_t \right] + \tau_y \widetilde{y}_t \right\}, \qquad (7)$$

where parameter ρ_i measures the degree of interest rate smoothing, τ_π denotes the responsiveness of the nominal interest rate to a weighted average of price and wage inflation, while τ_ω indicates the relative weight attached to wage inflation. Finally,

τ_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.[10]

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.

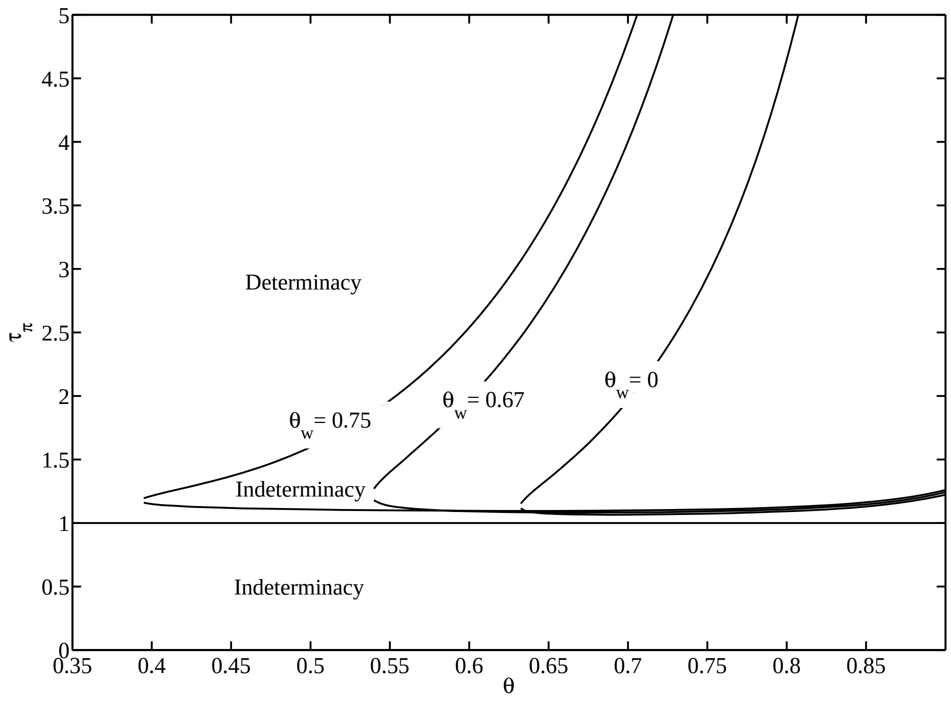

Figure 1: Indeterminacy with wage and price stickiness and firm-specific capital.

[10] 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 also had been 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.

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 ($\theta = 0.395$). Before we develop our intuition for that result the following remark might be in order. The dimension of indeterminacy is two for the region which corresponds to values of $\tau_\pi > 1$. In the absence of any additional assumptions it is therefore impossible to compute impulse responses to sunspot shocks for parameter values in that range, as shown in Galí (1997). The intuitions we outline next should therefore be interpreted in the following way. They isolate the role of capital accumulation for the determination of the marginal cost. The reason why we focus on this economic mechanism is as follows. If the capital stock is held constant at the firm-level then the Taylor principle is sufficient for determinacy. That leads to the following question. What are the quantitatively important changes in a NK model associated with the presence of firm-specific capital accumulation? First, the demand side does not change in any important way, as discussed in Clarida et al. (1999). Second, the *only* way in which firm-specific capital implies an important change in the supply side is the determination of the real marginal cost, as opposed to the dynamic relationship between marginal cost and inflation. We therefore believe that any plausible interpretation of the results shown in figure 1 has to rely on the particular way in which capital accumulation affects the determination of the marginal cost.

Let us now develop our intuition. An increase in investment demand has counteracting effects on the determination of the real marginal cost. 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.[11] 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. Related to that it is important to note that the future increase in labor productivity tends to decrease future labor demand since firms are demand constrained.[12] Forward-looking wage setters take this rationally into account when deciding upon current nominal wages. But the increase in real wages is an important driving force behind the initial increase in the real marginal cost when an investment boom kicks in. On the other hand, the subsequent reduction in the marginal cost is mainly driven by the increase in labor productivity, the second component of the marginal cost. 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

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

[12] Galí (1999) and Galí and Rabanal (2004) argue that the ability of sticky prices to elicit a negative response of labor demand to a shock that increases labor productivity is exactly the property which makes NK models appealing on empirical grounds.

and to wage inflation is larger than one. In our interest rate rule this corresponds to 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 that 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.

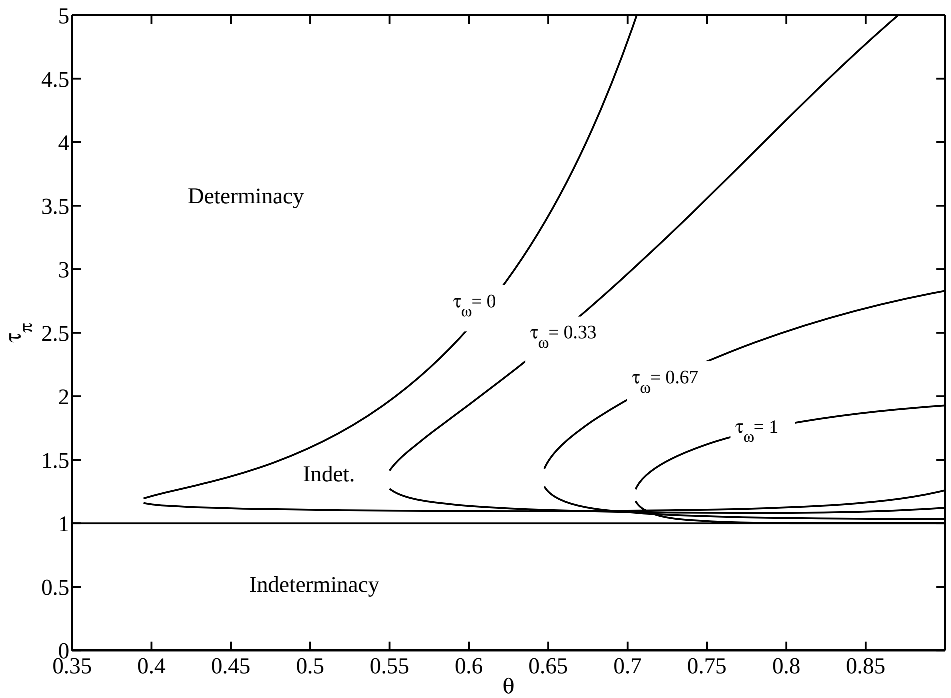

Figure 2: Indeterminacy when reacting to nominal wage inflation.

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.

We have mentioned already that the empirical evidence on price stickiness does not speak with a single voice. It is therefore interesting to note that for a value of the price stickiness parameter equal to 0.75, which corresponds to an average expected lifetime of a price equal to one year, there is still a non-standard indeterminacy region even if the weight attached to wage inflation is set equal to one. Our intuition is analogous to the one outlined above for the case in which the central bank reacts to price inflation only. The initial effect of an investment boom is an increase in labor demand, while – in the presence of sticky prices – there is also a future reduction in labor demand. Wage inflation inherits this dynamic pattern and under the assumed monetary policy the same is true for short term real rates. Since current wage setters take into account the future drop in labor demand the short term increase in nominal wages might not be large enough that the long term real rate increases.

4.4 The Case for Taylor-Type Rules

In our 2005b 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.

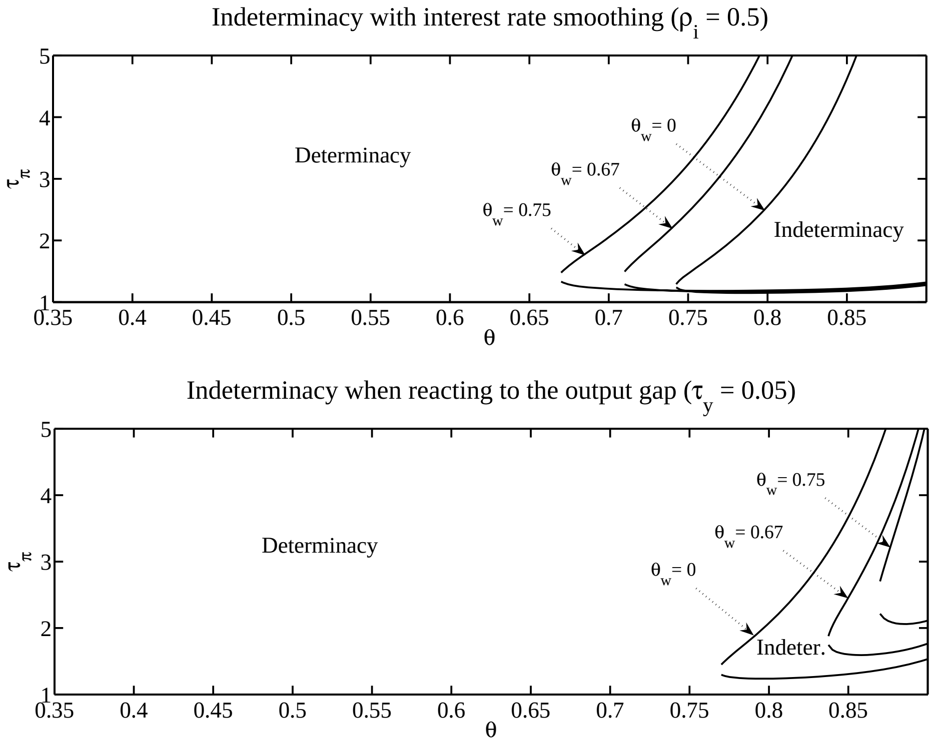

Figure 3: Indeterminacy with a Taylor type rule.

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 pointed out in our 2005b 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 conclusion that empirically plausible interest rate rules guarantee macroeconomic stability. Moreover, in related work, Sveen and Weinke (2006) find that Taylor-type rules are also desirable from a welfare point of view.

5 Conclusion

We show that the practical relevance of the indeterminacy problem discussed in Sveen and Weinke (2005b) 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.

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