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by

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Rule-of-thumb consumers, productivity and hours*

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Abstract

In this paper we study the transmission mechanisms of productivity shocks in a model with rule-of-thumb consumers. In the literature, this financial friction has been studied only with reference to fiscal shocks. We show that the presence of rule-of-thumb consumers is also very helpful in accounting for recent empirical evidence on productivity shocks. Rule-of-thumb agents, together with nominal and real rigidities, play an important role in reproducing the negative response of hours and the delayed responses of output and consumption after a productivity shock.

JEL Classification: E32. Keywords: rule-of-thumb consumers, productivity shocks, nominal rigidities, real rigidities.

1 Introduction

Recent research on fiscal policy in dynamic stochastic general equilibrium (DSGE) models has shown that deviations from Ricardian equivalence are instrumental in

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generating empirically plausible responses to government spending shocks. In particular, Galí et al. (2007) show that private consumption may rise after a positive shock to government spending if so-called rule-of-thumb consumers, who simply consume their current disposable income each period, are allowed to co-exist with intertemporally optimising consumers.[1] In the model, optimising consumers decrease their consumption following a government spending shock because they correctly anticipate a decline in life-time income as a consequence of taxation. But rule-of-thumb consumers increase their consumption if current disposable income increases. This happens in the model when the government finances the increase in its spending at least partially through the issuance of bonds, under assumptions of sticky prices and an imperfectly competitive labour market. In this case, if a sufficiently large fraction of households follow a rule of thumb, aggregate consumption rises.

A number of papers have further studied the implications of rule-of-thumb behaviour for fiscal policy in DSGE models, and rule-of-thumb consumers have become a standard ingredient in DSGE models at policy-making institutions, in particular at central banks.[2] But as far as we know, the implications of rule-of-thumb behaviour have not been investigated beyond the fiscal policy dimension so far. This is potentially important since rule-of-thumb consumers represent a substantial deviation from the standard optimising framework of DSGE models. In the baseline calibration in Galí et al. (2007), 50 per cent of households have no access to financial and capital markets and so cannot smooth consumption intertemporally. The market incompleteness introduced by this assumption may be suspected to have potentially

[1] To our knowledge, the idea that a fraction of consumers consume their current incomes each period, while the remaining fraction optimise intertemporally, was first put forward by Hall (1978) as an alternative to the permanent income hypothesis. Campbell and Mankiw (1989, 1991) reject the permant income hypothesis against this alternative, and Mankiw (2000) suggests that rule-of-thumb consumers should be included in models built for the analysis of fiscal policy issues.

[2] Papers include Andersen (2005), Bilbiie (2005), Coenen and Straub (2005), Colciago (2007), Erceg et al. (2006), Forni et al. (2007), Furlanetto (2007), Furlanetto and Seneca (2007), Galí et al. (2004) and Natvik (2006).

sizeable effects on the model's propagation of shocks to variables other than government spending. This is an important objection as counterfactual responses to other kinds of shocks may question the plausibility of introducing rule-of-thumb consumers even for analysing fiscal policy issues.

The purpose of this paper is to test this conjecture for the case of shocks to productivity. Hence, we analyse the impact of rule-of-thumb consumption behaviour on the propagation of technology shocks in the framework developed by Galí et al. (2007).[3] Considering the recent debate in macroeconomics on the importance of technology shocks for business cycle fluctuations, it seems particularly important to study the performance of the class of DSGE models with rule-of-thumb consumers in response to these shocks. On one hand, beginning with the seminal papers by Kydland and Prescott (1982) and Prescott (1986), real business cycle (RBC) theory suggests that technology shocks are the most important driving force behind business cycle fluctuations. On the other hand, a number of later papers, particularly Galí (1999), have challenged this claim based on empirical evidence on the impulse responses of macroeconomic variables. In this paper, we contribute to this debate by shedding light on how financial frictions in the form of rule-of-thumb behaviour may affect the transmission of technology shocks in the economy.

Galí (1999), and more recently Francis and Ramey (2005), provide evidence on responses to technology shocks in the US by identifying such shocks in an estimated vector autoregression (VAR) through long-run restrictions. In both studies, a positive technology shock has a significant negative effect on hours worked - in stark contrast with the predictions of the RBC literature. Furthermore, in both studies output does not respond to the shock on impact, but it increases with a lag. Since output and

[3] We have also considered the effects of monetary, preference and cost-push shocks. The model with rule-of-thumb consumers delivers results very similar to the model without them as long as wages are sticky. Wage rigidity effectively shuts down the mechanisms through which rule-of-thumb behaviour may change the propagation of these shocks. Results are available upon request.

hours are strongly positively correlated in the data, it follows that technology shocks cannot be the main driving force behind business cycle fluctuations.

Of course, these claims have not stood unchallenged. Christiano et al. (2004) and McGrattan (2004) argue that Galí's (1999) results are sensitive to small changes in the specification of the empirical model. When hours are introduced in levels, and not in first differences as in Galí (1999), these authors obtain a positive response of hours. However, in recent papers Fernald (2007) and Canova et al. (2007) show that once low-frequency movements in hours are taken into account, the negative response of hours is robust; see also Galí and Rabanal (2005) for a discussion. In addition, Gambetti (2005) confirms that hours fall using a bayesian VAR with time-varying coefficients. Consequently, we consider the evidence from the VAR literature to favour the view that hours decrease on impact of a technology shock.

An alternative empirical approach is taken by Basu et al. (2006). They use a sophisticated growth accounting framework to correct Solow residuals for the influences of increasing returns, imperfect competition, variable factor utilisation and sector compositional effects. Somewhat surprisingly, perhaps, this approach leads to results that are very similar to those of the VAR literature. In particular, Basu et al. (2006) estimate a significant decline in hours on impact of a technology shock, while they find a zero impact response of output.[4]

How can a theoretical model deliver a decline in hours after a technology shock? Galí (1999) shows how nominal rigidities, a key feature of New Keynesian models, can lead to such a response. However, Dotsey (2002) shows that this is true only if monetary policy is modelled as an exogenous money growth rule; when monetary policy follows a Taylor (1993) rule, hours increase as in the baseline RBC model.

[4] The evidence in Basu et al. (2006) is based on macrodata for the US. Interestingly, using firm-level data for Italy and Sweden, respectively, Marchetti and Nucci (2005) and Carlsson and Smedsaas (2006) find that firms reduce the input of labour on impact of a positive technology shock. See also Carlsson (2003).

Francis and Ramey (2005) show that an RBC model augmented with real rigidities (habit persistence in consumption and capital adjustment costs) can generate a negative response of hours without relying on nominal rigidities.[5] In this paper, we show that a financial friction represented by rule-of-thumb behaviour affects the model's transmission mechanism in a way that makes it easier to obtain a decline in hours on impact of a productivity shock. In addition, we show how rule-of-thumb behaviour interacts with the nominal and real rigidities that have previously been considered in literature as potential explanations of the negative response of hours.

The Galí et al. (2007) model is characterised by three rigidities, namely price stickiness, capital stickiness (due to capital adjustment costs) and the financial rigidity barring a fraction of households, the rule-of-thumb consumers, from access to financial and capital markets. We extend this framework in two steps.

In the first step, we extend the model with nominal wage rigidity as in Furlanetto (2007). Sticky wages have been shown to be important in order to generate plausible dynamics in macroeconomic variables in response to a wide variety of shocks, cf. Christiano et al. (2005). Moreover, Liu and Phaneuf (2005) show that sticky wages, in combination with sticky prices, are important in order to explain the dynamics of hours and wages following a productivity shock. The Galí et al. (2007) model extended with nominal wage rigidity is our baseline model.

In the second step, we introduce a fifth rigidity, namely consumption stickiness in the form of habit persistence in consumption. Habit formation has recently received a lot of attention in the literature, e.g. by Francis and Ramey (2005), Galí and Rabanal (2005) and Fève (2004). As we shall see, this extension allows us to explain empirical evidence on key macroeconomic variables besides hours and wages. In

[5] Galí and Rabanal (2005) estimate a New Keynesian model using Bayesian techniques, and they find that both nominal and real rigidities are important, while Galí et al. (2003) detect significant differences across periods in the Federal Reserve's responses to technology shocks, reconciling the results of Galí (1999) and Dotsey (2002).

addition, it allows us to analyse the role played by many of the frictions studied in the literature and their interaction with rule-of-thumb consumers. Building on the terminology of McGrattan (2004), we refer to the Galí et al. (2007) model extended with both nominal wage rigidity and habit persistence as the *quintuple*-sticky model.

This paper's first key result is that the model with rule-of-thumb consumers is able to reproduce a sizeable decline in hours in keeping with the empirical evidence. Like Galí and Rabanal (2005), we find that a model with three types of rigidities (sticky prices, sticky wages and capital adjustment costs) can reproduce a negative response of hours - even under endogenous monetary policy in the form of a Taylor rule. But we show that this response is very small. As shown in figure 1, a one per cent increase in technology leads to a 0.2 per cent decline in hours worked on impact under our preferred calibration. In our baseline model with rule-of-thumb consumers, hours decline more: -0.6 per cent. Thus, the model's response coincides with the estimates in Basu et al. (2006) and Francis and Ramey (2005).

The intuition is the following. A positive shock to technology means that firms can produce a given level of output with fewer hours. Because prices are sticky, the level of output is determined by demand. This means that hours will go down if demand does not increase sufficiently after the shock. As to government spending shocks, rule-of-thumb and optimising households react to technology shocks in different ways. Optimising consumers correctly anticipate an increase in life-time income and so they increase their consumption. This works to offset the decline in hours through aggregate demand. Rule-of-thumb consumers, in contrast, see current income go down because of combined effects of sticky prices and wages, and this makes them consume less. This curbs the aggregate demand effect, and hours decline more as a result when some households consume according to a rule of thumb. In a nutshell, our financial rigidity amplifies the impact of nominal and real rigidities, making the transmission more contractionary.

While the literature has studied the response of hours to technology shock in great detail, less attention has been devoted to the responses of other macroeconomic variables. Both Basu et al. (2006) and Francis and Ramey (2005) find not only a decline in hours on impact of a technology shock, but also a zero response of both output and consumption. Surprisingly, this additional evidence suggesting a delayed expansion in output and consumption following a technology improvement is yet to be explained in the theoretical literature.

The second key result of this paper is that the *quintuple*-sticky model can reproduce the zero impact-responses of output and consumption found in Basu et al. (2006) and Francis and Ramey (2005) in addition to a decline in hours worked. In the model, habit persistence works to smooth consumption, in effect delaying the full response of consumption to shocks. We stress, however, that the presence of all the five rigidities considered is crucial to obtain this result.

Consequently, rule-of-thumb agents are instrumental not only in obtaining a large negative response of hours, but also in reproducing delayed responses of output and consumption as in the empirical evidence. Thus, rule-of-thumb consumers, representing a substantial deviation from the standard optimising DSGE framework, do not worsen the performance of the model. In contrast, they can be very helpful in replicating important empirical regularities. This implies that researchers may safely rely on rule-of-thumb consumers in fiscal policy analyses in the sense that rule-of-thumb consumption behaviour generates reasonable responses to other shocks.

The paper has the following structure. In section 2 we briefly present the baseline model, and in section 3 we present impulse responses to technology shocks from this version of the model. In section 4 we discuss the *quintuple*-sticky model, we compare our results to other papers in the literature, and we present a sensitivity analysis. Section 5 concludes.

2 A DSGE model with rule-of-thumb consumers

The model is a standard New Keynesian model augmented with capital and rule-of-thumb consumers as in Galí et al. (2007), and with sticky wages as in Furlanetto (2007).[6] The economy consists of a continuum of firms, a continuum of households, a continuum of labour unions, a central bank responsible for monetary policy, and a government collecting lump-sum taxes.[7]

There is monopolistic competition in both goods and labour markets. In particular, there is a continuum of differentiated intermediate goods and a continuum of differentiated labour services. In the goods market, this leads to a downward-sloping demand curve for each intermediate good, and in the labour market it leads to a downward-sloping demand curve for each labour type.

A fraction λ of households are rule-of-thumb consumers - or 'spenders' in the terminology of Mankiw (2000). These consumers simply consume their respective disposable incomes each period. The remaining fraction $(1 - \lambda)$ of households are optimisers - or 'savers' - who have access to both financial and capital markets. Hence, they choose plans for consumption, investment and bond holdings to maximise lifetime utility. Wages are set by unions that each represent a differentiated type of labour service supplied by households. Wage rigidity is introduced by assuming adjustment costs as in Rotemberg (1982).

Each firm produces one of the differentiated intermediate goods. It does so by combining rented capital with a homogenous labour input constructed as a Dixit and Stiglitz (1977) aggregate of the differentiated labour services supplied by households. The firm sets its price according to a Calvo (1983) price-setting mechanism and stands ready to satisfy demand at the chosen price.

[6] In the appendix we further extend the model with habit formation in consumption.

[7] We abstract from fiscal policy as the model's propagation of government spending shocks has been thoroughly analysed in the literature, cf. references above.

Each period begins by the realisation of shocks to the economy. We concentrate on technology shocks and abstract from other types of shocks that may affect the economy.

2.1 Households

Households have identical instantaneous utility functions

$$U_t^i = \frac{\left(C_t^i\right)^{1-\sigma} - 1}{1-\sigma} - \frac{\left(N_t^i\right)^{1+\varphi}}{1+\varphi} \tag{1}$$

where $i \in \{o, r\}$ denotes the household's type, i.e. optimising or rule-of-thumb. C_t^i is the household's real consumption at time t (implicitly a Dixit and Stiglitz, 1977, index of intermediate goods), N_t^i is the hours worked by the household in period t, $\varphi > 0$ is the inverse of the Frisch labour elasticity, and $\sigma > 0$ is the coefficient of relative risk aversion and, at the same time, the inverse of the elasticity of intertemporal substitution.

An optimising household maximises expected life-time utility given by

$$E_t \sum_{k=0}^{\infty} \beta^k U_{t+k}^o$$

where E_t is an operator representing expectations over all states of the economy conditional on period-t information, and $\beta \in (0, 1)$ is the subjective discount factor. Maximisation is subject to a sequence of flow budget constraints (and implicitly a no-Ponzi game condition):

$$P_t \left(C_t^o + I_t\right) + E_t \left(\Lambda_{t,t+1} B_{t+1}\right) = W_t N_t^o + R_t^k K_t + B_t - P_t T_t^o - F_t$$

where I_t is real investment, W_t is the nominal wage, R_t^k is the nominal rental rate on the stock of capital owned by the household at the beginning of period t, K_t, and T_t^o is the real lump-sum tax paid by optimising consumers. The right-hand side gives available resources as the sum of labour income, $W_t N_t^o$, income from renting capital to firms, $R_t^k K_t$, initial financial wealth, B_t, less nominal lump-sum taxes paid to the government, $P_t T_t^o$, and less a nominal union membership fee, F_t. On the left-hand side, resources are allocated to consumption, investment and a portfolio of bonds, $E_t\left(\Lambda_{t,t+1} B_{t+1}\right)$. $\Lambda_{t,t+1}$ is the stochastic discount factor. Hence, the gross risk-free interest rate is given by the relation $1 + R_t = \left(E_t \Lambda_{t,t+1}\right)^{-1}$.

The household's capital evolves according to

$$K_{t+1} = (1 - \delta) K_t + \phi\left(\frac{I_t}{K_t}\right) K_t$$

where δ is the rate of depreciation, and $\phi(.)$ is an adjustment cost function satisfying $\phi(\delta) = \delta$, $\phi' > 0$, $\phi'(\delta) = 1$ and $\phi'' \leq 0$.

The optimisation problem, according to which the household chooses plans for consumption, bond holdings and investment, gives rise to the following first-order conditions that we state in log-linear form:[8]

$$c_t^o = E_t c_{t+1}^o - \frac{1}{\sigma}\left(r_t - E_t \pi_{t+1}\right) \tag{2}$$

$$k_{t+1} = (1 - \delta) k_t + \delta i_t \tag{3}$$

$$q_t = -\left(r_t - E_t\left[\pi_{t+1}\right]\right) + \left[1 - \beta(1 - \delta)\right] E_t\left[r_{t+1}^k - p_t\right] + \beta E_t\left[q_{t+1}\right] \tag{4}$$

$$i_t - k_t = \eta q_t \tag{5}$$

where $\eta \equiv -1/\left(\phi''(\delta)\,\delta\right)$. Here, (2) is the Euler equation, (3) is the capital accumulation equation, while (4) and (5) represent the dynamics of Tobin's q, denoted q_t,

[8]For details on the derivation we refer the reader to GLV (2007). Lowercase variables denote log-deviations from the steady state of the corresponding uppercase variables.

and its relation to investment, respectively.

A rule-of-thumb household faces the simple budget constraint

$$P_t C_t^r = W_t N_t^r - P_t T^r - F_t$$

where C_t^r is the household's real consumption at time t, N_t^r is the hours worked by the household in period t, and F_t is a nominal union membership fee. As a rule-of-thumb household simply consumes its current income, consumption follows directly from the budget constraint. A first-order log-linear approximation around the steady state with constant consumption equalised across households gives

$$c_t^r = \frac{WN}{PC} \left(w_t + n_t\right) \tag{6}$$

where omission of time subscripts indicate steady-state variables. Note that taxes drop out of the first-order approximation because we abstract from government spending shocks. Also, the union membership fee drops out because the fee is assumed to be a quadratic function of wage inflation, which is zero in the steady state, cf. below.

Aggregate variables are given as simple weighted averages:

$$c_t = \lambda c_t^r + (1 - \lambda)\, c_t^o \tag{7}$$

$$n_t = \lambda n_t^r + (1 - \lambda)\, n_t^o \tag{8}$$

2.2 Firms

Each firm produces according to the technology

$$Y_t = A_t K_t^{\psi} N_t^{1-\psi}$$

where Y_t is output, A_t is a technology shock, and $0 \leq \psi \leq 1$. Each period, a firm is allowed to set a new price, P_t^*, with a fixed probability $(1-\theta_p)$ as in Calvo (1983). It does so to maximise the value of the firm to its owners, the optimising households,

$$\sum_{k=0}^{\infty} \theta^k E_t \left[\Lambda_{t,t+k} \left(P_t^* Y_{t+k|t} - W_{t+k} N_{t+k|t} - R_{t+k}^k K_{t+k|t} \right) \right]$$

where subscript $t+k|t$ indicates the value of the variable at time $t+k$ for a firm that has last reset its price in period t. Maximisation is subject to the downward-sloping demand curve it faces as a consequence of monopolistic competition.

As is wellknown, the optimality conditions from this problem imply the New Keynesian Phillips curve

$$\pi_t^p = \beta E_t \left(\pi_{t+1}^p \right) + \kappa_p mc_t \tag{9}$$

where $\kappa = (1-\beta\theta_p)(1-\theta_p)\theta_p^{-1}$, $\pi_t^p = p_t - p_{t-1}$ is price inflation, and where mc_t is real marginal costs given by

$$mc_t = (w_t - p_t) - (y_t - n_t) \tag{10}$$

In addition, cost minimisation implies that relative factor inputs satisfy the condition

$$k_t - n_t = (w_t - p_t) - \left(r_t^k - p_t \right) \tag{11}$$

Up to a first-order approximation, production is given by

$$y_t = a_t + \psi k_t + (1 - \psi) n_t \tag{12}$$

2.3 Labour Unions

The economy has a continuum of unions $z \in [0, 1]$ each representing a continuum of workers. A fraction $(1 - \lambda)$ are optimising, and fraction λ are rule-of-thumb consumers. Each union sets the wage rate for its members, who stand ready to satisfy firms' demand for their labour services at the chosen wage. The workers in a union provide the same type of labour (irrespective of their consumption behaviour) differentiated from the type of labour services provided by members of other unions. The labour service supplied by each union, $N(z)$, is a simple aggregate of its members' labour services. In turn, the labour entering the production function of any firm is a Dixit and Stiglitz (1977) aggregate of the labour services provided by the unions in the economy.

Each period, a representative union chooses $W_t(z)$ to maximise the present value of an average of its members' current and future period utility functions, that is,

$$\max_{W_t(z)} E_t \sum_{k=0}^{\infty} \beta^{t+k} \left[\lambda U_{t+k}^r + (1 - \lambda) U_{t+k}^o \right]$$

subject to the labour demand functions and the budget constraints of its members, thus taking the effect of the wage decision on the income of its members into account. Wage adjustments are assumed to be costly. In particular, it is assumed that the wage adjustment cost is a quadratic function of the increase in the wage demanded by the union as modelled in Rotemberg (1982) for prices demanded by firms. For simplicity, the adjustment cost is proportional to the aggregate wage bill in the economy (this parallels the specification of price adjustment costs in Ireland, 2003). Though the wage bargaining process is not explicitly modelled, one way of thinking of this cost is that unions have to negotiate wages each period and that this activity demands economic resources; the larger the increase in wages obtained, the more effort unions would have needed to put into the negotiation process. Each member of the union covers an equal share of the wage adjustment cost by paying a union membership fee. Hence, the nominal fee paid by a member of union z at time t is given by

$$F_t(z) = \frac{\phi_w}{2}\left(\frac{W_t(z)}{W_{t-1}(z)} - 1\right)^2 W_t N_t$$

where the size of the adjustment costs is governed by the parameter ϕ_w.

The optimality conditions imply a New Keynesian Phillips curve for wage inflation given by

$$\pi_t^w = \beta E_t\left(\pi_{t+1}^w\right) + \kappa_w\left(mrs_t - (w_t - p_t)\right) \tag{13}$$

where mrs_t is the average marginal rate of substitution given by

$$mrs_t = \sigma c_t + \varphi n_t \tag{14}$$

and the slope coefficient κ_w is

$$\kappa_w = \frac{\varepsilon_w - 1}{\phi_w}$$

The derivation is given in the appendix.[9]

In the special case where $\phi_w = 0$, the model effectively collapses to the model

[9] Instead of wage adjustment costs, we may assume that a union is allowed to reset its wage rate each period with a fixed probability $(1-\theta_w)$ as in Calvo (1983). But to undo the implications of the implied heterogeneity across unions, each household must be assumed to provide all types of labour simultaneously in this case, or alternatively a risk-sharing arrangement between unions must be in place. This follows since rule-of-thumb consumers are barred from sharing risk through financial markets. Results, however, are very similar. In particular we would get a Phillips curve with $\kappa_w = (1-\beta\theta_w)(1-\theta_w)\theta_w^{-1}(1+\varphi\varepsilon_w)^{-1}$ where ε_w is the wage elasticity of labour demand.

in Galí et al. (2007). Firms do not discriminate between consumer types in their labour demand, and so it follows from the unions' problems that $n_t^r = n_t^o = n_t$.

2.4 Monetary policy

The central bank controls the risk-free interest rate, which it sets according to a simple Taylor rule

$$r_t = r + \phi_\pi \pi_t \tag{15}$$

This specification implies that monetary policy is endogenous. The central bank responds to inflation, which is endogenously determined in the economy.

2.5 Equilibrium

Market clearing requires that

$$Y_t = C_t + I_t + G + F_t$$

where $G = T$ is government spending. In log-linear form, this becomes

$$y_t = \frac{C}{Y} c_t + \frac{I}{Y} i_t \tag{16}$$

The only shocks to the economy that we consider are technology shocks. They evolve according to an autoregressive process of order one:

$$a_t = \rho_a a_{t-1} + e_{a,t} \tag{17}$$

It follows that the equilibrium dynamics are summarised by (2)-(17).

3 Impulse response analysis

In this section, we present impulse responses of key variables in a calibrated version of the model. To facilitate comparison, our calibration follows Galí et al. (2007). Hence, we consider a time period to be a quarter, and we set $\lambda = 0.5$, $\sigma = \eta = 1$, $\theta_p = 0.75$, $\psi = 0.3$, $\delta = 0.025$ and $\beta = 0.99$. In addition, we set $G/Y = 0.20$ with the implication that $I/Y = \alpha\delta\left(1/\beta + \delta\right)^{-1}\mu_p^{-1} = 0.18$, $C/Y = 0.62$ and $WN/PC = (1-\alpha)\, Y/C\mu_p$, under the assumption that steady-state price mark-ups $\left(\mu_p - 1\right)$ are 20 per cent, cf. Galí et al. (2007). However, we deviate from the calibration in Galí et al. (2007) in setting $\varphi = 1$ instead of $\varphi = 0.2$, a value we consider to be unrealistically low. Galí et al. (2007) need to set a high value for the labour elasticity to ensure determinacy of the equilibrium. But the introduction of wage rigidities increases the range of values of φ for which the equilibrium is determinate, cf. Colciago (2007). This allows us to set a more realistic value. Finally we set $\varepsilon_w = 4$ and $\phi_w = 174.7$. This corresponds to a steady-state wage mark-up of approximately 33 per cent, and a degree of price rigidity corresponding to $\theta_w = 0.75$ under the alternative Calvo (1983) wage-setting scheme, i.e. an average duration of wage contracts of four quarters.

We are interested in the implications of introducing rule-of-thumb consumers into the New Keynesian model, and so we compare the responses under the baseline calibration above with a calibration in which $\lambda = 0$, corresponding to a version of the model without rule-of-thumb consumers.

Figure 2 presents responses to a one standard deviation technology shock $\rho_a = 0.9$. Dashed lines are responses from the baseline model presented in the previous section, whereas solid lines are responses from the model without rule-of-thumb consumers.

Comparing the dashed and the solid lines, it is clear that the introduction of rule-of-thumb consumers is not without consequence for the responses to a technology shock. In particular, hours decline more following a positive productivity shock in the economy with rule-of-thumb behaviour in keeping with the empirical evidence in Basu et al. (2006) and Francis and Ramey (2005). Indeed, with our baseline calibration, hours go down by -0.6 per cent in the period when the technology shock hits the economy. This coincides with the estimate in Basu et al. (2006) and Francis and Ramey (2005).

The transmission is as follows. The increase in productivity lowers firms' marginal costs. If prices were flexible, firms would lower their prices and increase supply. But since prices are sticky, some firms cannot do so and the reduction in the overall price level is limited. This means that output increases less than it would had prices been flexible. In addition, hours decline because the improvement in technology allows firms to produce the same output as before with less labour. The monetary policy authority reacts to the reduction in prices by a measured reduction of the nominal interest rate.

The fall in the interest rate makes it optimal for consumers to consume more in the current period. Optimising consumers realise this, and they also correctly anticipate that the productivity shock leads to an increase in permanent income. These two forces make optimising consumers increase their consumption.

Rule-of-thumb consumers behave differently, however. As their horizon is static, neither the increase in permanent income nor the reduction in real interest rates affects their consumption decisions. Instead, they choose consumption on the basis of current income, which is determined by current hours in production and the real wage. As noted above, hours decline because prices are sticky, but real wages respond little as a consequence of sticky wages. Hence, the decline in hours is larger than the increase in real wages, and current income declines. This makes rule-of-thumb agents consume less.

The effect on aggregate consumption depends on the relative importance of optimising and rule-of-thumb consumers in the economy, and on the size of their responses to the shocks. Aggregate consumption may still rise despite rule-of-thumb behaviour, but the presence of households that do not optimise intertemporally has an important contractionary effect. The aggregate demand effect that could potentially offset the initial reduction in hours is smaller because rule-of-thumb consumers decrease their consumption. From figure 2 we see this effect clearly: The model with rule-of-thumb consumers exhibits a smaller increase in aggregate consumption and output than the model without rule-of-thumb behaviour, and it exhibits a larger decline in hours.

This leads us to the first key result of this paper. A model with rule-of-thumb consumers, interacting with nominal and real rigidities, can better explain the empirical evidence provided by Basu et al. (2006) and Francis and Ramey (2005). This is so even though the shock is too expansionary compared to the data.

We note that sticky wages is an essential assumption needed to obtain this result. In a model with flexible wages the increase in the real wage would be larger than the decrease in hours and rule-of-thumb agents would increase their level of consumption. There would be no contractionary effect from rule-of-thumb behaviour in this case.

Indeed, it is important to stress that all four frictions - sticky prices, sticky wages, rule-of-thumb behaviour and capital adjustment costs - are essential to subdue the expansionary effect of the shock. Sticky prices are needed for a decline in hours, and sticky wages are needed for this to lead to a reduction in the current income of rule-of-thumb consumers. A sufficiently high fraction of rule-of-thumb consumers, then, is needed for this reduction in current income to have an effect on the aggregate economy. And finally, capital adjustment costs are needed to dampen investment, an increase in which would otherwise offset the contractionary effect from the response of rule-of-thumb consumers.

Finally, we note that the real wage increase in the model with sticky wages perfectly fits the empirical evidence on the real wage response provided in Liu and Phaneuf (2005), whereas the response of the real wage in the model with flexible wages would be excessively procyclical. In our opinion, this fact is further confirmation that sticky wages is a sensible assumption.

From the analysis in this section, we conclude that the introduction of rule-of-thumb consumers, a considerable change to the standard DSGE set-up, does not lead to counterfactual responses to productivity shocks. On the contrary, (to the extent that a productivity shock leads to a decline in hours on impact) we find that the model's transmission mechanism is *improved*.

It is important to stress, however, that we perform a conditional analysis in the spirit of Galí (1999) and not an unconditional exercise as is typical in the RBC literature. That is, it is not our goal to reproduce the unconditional moments found in the data. Indeed, given the response of hours, our one-shock model would perform very badly in such an exercise. As in Galí (1999), Galí and Rabanal (2005) and Francis and Ramey (2005), productivity shocks are not the main driving force of aggregate fluctuations in our model.[10] Nevertheless, we believe that our conditional analysis is relevant in order to evaluate the effects of rule-of-thumb behaviour. Even if productivity shocks are not the *main* driving force behind the business cycle, they still represent a source of fluctuations in the economy that needs to be considered in detail, especially because of the prominent role played by these shocks in the RBC literature.

4 Quintuple stickiness

In this section we present results from the model in section 2 extended with habit formation in consumption. That is, we let utility today depend not on consumption

[10] To improve the unconditional performance of the model, we should include shocks to other variables such as demand shocks or possibly investment-specific technology shocks as in Fisher (2006).

today by itself, but on consumption today relative to consumption in the previous period. This makes optimising households look back as well as forward when making consumption decisions. In addition, unions take the effect of habit on the utility of its members into account when setting wages. Thus, the introduction of habit formation in consumption changes the Euler equation of optimising consumers and the wage-setting equation. Details are given in the appendix.

Our model's *quintuple* stickiness makes our analysis more comprehensive than previous studies of technology shocks. In particular, we model the capital accumulation process explicitly, and we introduce endogenous monetary policy by letting the model's central bank respond to inflation developments. In comparison, Galí and Rabanal (2005) ignore investment dynamics in their model, while Francis and Ramey (2005) let monetary policy be exogenous. Finally, we consider the implication of credit constraints by allowing for rule-of-thumb behaviour.

The analysis of the *quintuple*-sticky model serves two purposes. First, the model helps us explain the empirical evidence on key macroeconomic variables besides hours worked. Second, it allows us to analyse the roles played by many of the frictions studied in the literature on technology shocks and the interaction of these frictions with rule-of-thumb consumers. We consider each of these issues in turn.

4.1 Output, consumption and investment

The model presented in the previous section can easily reproduce the decline in hours after a technology shock found in the empirical literature. In addition, the response of the real wage seems plausible given the empirical evidence. But the model fares less well when considering other key macroeconomic variables for which we have empirical evidence. In particular, output, consumption and investment all increase on impact of a shock to technology in the model. This is in contrast to the evidence in Basu et al. (2006), who find that output and consumption change little on impact of a technology shock before increasing in the periods following the shock, whereas non-residential investment falls sharply on impact before rising. Francis and Ramey (2005) find similar responses for output and consumption, whereas the response of investment is statistically insignificant in their analysis.

Figure 3 presents the second key result in this paper. The *quintuple*-sticky model with rule-of-thumb consumers (dashed lines) can reproduce the zero impact responses of output and consumption. This is because habit persistence slows down the response of optimising consumers. With habit formation in consumption, optimising consumers need time to appreciate the increased scope for consumption given to them by the positive shock to technology. This leads to a hump-shaped response of optimising household's consumption, further restraining the expansion in the economy.

Now, perhaps the contractionary effects are even too strong in our *quintuple*-sticky model with rule-of-thumb consumers; hours go down more than one per cent, and aggregate consumption actually declines. However, as we show below, we may undo this excess contraction by modifying the baseline calibration, e.g. by lowering the percentage of rule-of-thumb consumers or the degree of price stickiness.[11] Here we keep the parameter values chosen by Galí et al. (2007) to facilitate comparison. An estimated model could deliver more precise guidance on the parameter values needed to replicate the empirical results. Our objective here is simply to show that the *quintuple*-sticky model with rule-of-thumb consumers delivers a very contractionary propagation of technology shocks, and that a financial friction in this form provides an additional explanation, along with nominal and real rigidities, of why a productivity shock may lead to a decline in hours on impact.

[11] Indeed, given the empirical evidence, both these parameters may appear to be uncomfortably high in our baseline calibration. For a discussion, see Furlanetto and Seneca (2007).

Figure 3 also shows responses to a technology shock for the model without rule-of-thumb consumers (solid lines). We see that rule-of-thumb behaviour is crucial in order to replicate the zero impact responses found in empirical studies. Without this friction, both output and consumption increase on impact of the shock.

Turning to investment, Basu et al. (2006) find a significantly negative response of this variable after a productivity shock. Given our analysis, this is puzzling. Indeed, investment increases after a positive technology shock in all versions of the model. In particular, the positive response of investment is not related to the presence of rule-of-thumb consumers. Basu et al. (2006) argue that their evidence on investment is compatible with a sticky price model in the case where monetary policy is exogenous. Once we allow for an endogenous reaction from the monetary authority, the response of investment is always both positive and fairly large. We believe that our assumption about monetary policy is the more reasonable one, however, and the evidence provided by Galí et al. (2003) supports this claim.

The identifying assumption often used in the empirical VAR literature is that a technology shock has a permanent effect on labour productivity. Therefore, we check whether a permanent technology shock delivers the same results as the temporary (but highly persistent) shock considered above. This is confirmed in figure 4. In particular, the impact responses of hours, the real wage, consumption and output are in line with the estimated responses in Basu et al. (2006) and Francis and Ramey (2005).

4.2 Interacting frictions and sensitivity analysis

It is important to note that all the frictions in the *quintuple*-sticky model are needed to obtain the results just considered. In figure 5, we show impulse responses to a (temporary, highly persistent) technology shock for the model with nominal rigidities only (sticky wages and sticky prices) and for the model with real rigidities only (capital adjustment costs and habit persistence), in both cases without rule-of-thumb consumers. We see that the model with nominal rigidities only (solid lines) performs poorly. Consumption, output, hours and investment all increase sharply following the technology shock. This is because, without capital adjustment costs, a technology shock leads to an investment boom that more than offsets the contractionary effect from other frictions in the model. In keeping with the theoretical results in Francis and Ramey (2005), the model with real rigidities only (dashed lines) is able to reproduce a decline in hours, but output, consumption and investment responses are too expansionary compared to those estimated by Basu et al. (2006) and Francis and Ramey (2005).

Figure 5 confirms that real, nominal and financial frictions are all important to obtain a sizeable negative response of hours and a zero impact response of output and consumption. The same message comes from the more careful sensitivity analysis for the *quintuple*-sticky model that we present in figure 6. There, we plot the impact responses of output, consumption and hours for a large spectrum of parameter values to our temporary, but highly persistent technology shock. If lines are flat, it means that impact responses are not affected by the specific parameter considered.[12]

From figure 6 we see that the labour supply elasticity and the habit persistence parameter for constrained agents do not influence impact responses. The other panels confirm that impact responses are declining in the percentage of rule-of-thumb consumers, in the degree of wage and price rigidity, and in the degree of habit persistence in optimising consumption. Notice that the excess contraction in consumption disappears if λ is close to 0.25 instead of 0.5 as in the baseline calibration, or if we let θ_p be in the region of 0.6 instead of 0.75. The results for the coefficient in the Taylor

[12] The analysis is partial in the sense that we vary one parameter at a time, while the remaining parameters are fixed at the values chosen for the baseline calibration.

rule suggest that the central bank will have to be very aggressive to overturn the results. On a similar note, if σ is very low, optimising consumers respond strongly to monetary policy and the contractionary effect from rule-of-thumb behaviour carries less weight at the aggregate level. Finally, when η is high it means that capital adjustment costs are low, in which case all the impact responses become positive. Again, this is because investment overreacts when prices are sticky and capital adjustment costs are low. Thus, figure 6 confirms that all five frictions in the model are needed to curb the expansionary effects of positive shocks to technology.

5 Conclusion

The introduction of rule-of-thumb consumers into the New Keynesian DSGE model has proven to be a useful way to explain responses to fiscal shocks. The purpose of this paper is to check whether the introduction of this substantial financial friction affects the transmission mechanism of productivity shocks.

We find that rule-of-thumb consumers, in combination with real and nominal rigidities, can explain a sizeable decline in hours worked after a positive productivity shock as suggested by the empirical evidence in Galí (1999), Francis and Ramey (2005) and Basu et al. (2006).

Moreover, we show that within our *quintuple*-sticky business cycle framework, only a combination of nominal rigidities, real rigidities and limited access to financial markets can reproduce a sizeable negative effect on hours *and* a zero impact response of output and consumption.

In addition, our *quintuple*-sticky model is a useful laboratory in which to compare results from many other papers in the literature. A model with real rigidities alone can explain a negative effect on hours, but the inclusion of a financial friction interacting with nominal rigidities is essential in order to reproduce a zero impact effect on output and consumption. A model with nominal rigidities alone cannot explain a decline in hours.

We conclude that the transmission mechanism for technology shocks is improved by including rule-of-thumb consumers in the model. Thus, our analysis suggests that researchers may safely build rule-of-thumb consumers into their models to reproduce empirically plausible responses to fiscal policy shocks without having to fear that the model becomes less realistic in other dimensions. Indeed, this financial friction may be an additional explanation, along with nominal and real rigidities, of why hours may decline following a productivity shock as the empirical literature suggests. An important topic for future empirical research is to investigate the relative importance of these frictions. In future work we therefore plan to estimate the *quintuple*-sticky model using Bayesian techniques.

A Appendix

Derivation of the wage schedule. The first-order condition to the union's problem becomes

$$
\begin{aligned}
0 &= \lambda \frac{\partial U_t^r}{\partial C_t^r} \frac{\partial C_t^r}{\partial W_t(z)} + (1-\lambda) \frac{\partial U_t^o}{\partial C_t^o} \frac{\partial C_t^o}{\partial W_t(z)} - (N_t(z))^{\varphi} \frac{\partial N_t(z)}{\partial W_t(z)} \\
&\quad + \beta E_t \left[\lambda \frac{\partial U_{t+1}^r}{\partial C_{t+1}^r} \frac{\partial C_{t+1}^r}{\partial W_t(z)} + (1-\lambda) \frac{\partial U_{t+1}^o}{\partial C_{t+1}^o} \frac{\partial C_{t+1}^o}{\partial W_t(z)} \right]
\end{aligned}
$$

Since the demand for union z's type of labour service is given by the usual relation (implied by the Dixit-Stiglitz aggregator)

$$
N_t(z) = \left(\frac{W_t(z)}{W_t} \right)^{-\varepsilon_w} N_t
$$

we have

$$
\frac{\partial N_t(z)}{\partial W_t(z)} = -\varepsilon_w \frac{N_t(z)}{W_t(z)}
$$

and from the budget constraints we get

$$
\frac{\partial C_t^i}{\partial W_t(z)} = \frac{1}{P_t} \left[(1-\varepsilon_w) N_t(z) - \phi_w \left(\frac{W_t(z)}{W_{t-1}(z)} - 1 \right) \frac{W_t N_t}{W_{t-1}(z)} \right]
$$

and

$$
\frac{\partial C_{t+1}^i}{\partial W_t(z)} = \frac{1}{P_{t+1}} \phi_w \left(\frac{W_{t+1}(z)}{W_t(z)} - 1 \right) \frac{W_{t+1}^2}{(W_t(z))^2} N_{t+1}
$$

for $i \in \{o, r\}$.

Inserting these expressions in the first-order condition, imposing symmetry so that $W_t(z) = W_t$ and $N_t(z) = N_t$ for all z, and rearranging gives

$$\begin{aligned} 0 &= \left(\lambda \frac{\partial U_t^r}{\partial C_t^r} + (1-\lambda)\frac{\partial U_t^o}{\partial C_t^o}\right)\frac{W_t}{P_t}\left[(1-\varepsilon_w) - \phi_w\left(\Pi_t^w - 1\right)\Pi_t^w\right] + \varepsilon_w N_t^{\varphi} \\ &\quad + \beta E_t\left[\left(\lambda \frac{\partial U_{t+1}^r}{\partial C_{t+1}^r} + (1-\lambda)\frac{\partial U_{t+1}^o}{\partial C_{t+1}^o}\right)\phi_w\left(\Pi_{t+1}^w - 1\right)\Pi_{t+1}^w \frac{W_{t+1}}{P_{t+1}}\frac{N_{t+1}}{N_t}\right] \end{aligned}$$

where $\Pi_t^w = W_t/W_{t-1}$ and

$$\frac{\partial U_t^i}{\partial C_t^i} = \left(C_t^i\right)^{-\sigma}$$

when the instantaneous utility is given by (1). Log-linearising gives (13) in the text.

Habit persistence. With habit persistence in consumption, the instantaneous utility function of a household is given by

$$U_t^i = \frac{\left(C_t^i - h_i \bar{C}_{t-1}^i\right)^{1-\sigma} - 1}{1-\sigma} - \frac{\left(N_t^i\right)^{1+\varphi}}{1+\varphi}$$

where $i \in \{o, r\}$ and $\bar{C}_{t-1}^i$ denotes aggregate consumption by households of type i at time t. The degree of habit in consumption is governed by the parameter h_i. With this specification, habit formation is external with respect to the household itself in the sense that the household ignores the effect of its current consumption choice on the lagged consumption term that enters the utility function next period. But habit formation is internal with respect to the type of household since the lagged consumption term is aggregate consumption by the class of households to which the household belongs as opposed to aggregate consumption by all households in the economy. In the limiting case where $h_i = 0$, there is no habit formation for a household of type i.

With habit formation, the marginal utility of consumption becomes

$$\frac{\partial U_t^i}{\partial C_t^i} = \left(C_t^i - h_i \bar{C}_{t-1}^i\right)^{-\sigma} = \left(C_t^i - h_i C_{t-1}^i\right)^{-\sigma}$$

where the last equality follows from the fact that all households of a given type are identical so that $C_t^i = \bar{C}_t^i$ for all t. Using this expression in the union's first-order condition and log-linearising gives (13) in the text only that now (14) must be replaced by

$$mrs_t = \chi_r \left(c_t^r - h_r c_{t-1}^r\right) + \chi_o \left(c_t^o - h_o c_{t-1}^o\right) + \varphi n_t \tag{18}$$

where

$$\chi_r = \sigma \frac{\lambda}{1-h_r} \frac{(1-h_o)^\sigma}{\lambda (1-h_o)^\sigma + (1-\lambda)(1-h_r)^\sigma}$$

and

$$\chi_o = \sigma \frac{(1-\lambda)}{1-h_o} \frac{(1-h_r)^\sigma}{\lambda (1-h_o)^\sigma + (1-\lambda)(1-h_r)^\sigma}$$

Note that for $h_r = h_o = 0$ this is identical to (14) in the text. For $h_r = h_o = h > 0$, we get $\chi_r = \lambda / (1-h)$ and $\chi_o = (1-\lambda)/(1-h)$. We generally assume that $h_r = 0$ and $h_o > 0$.

Habit persistence also changes the optimising household's stochastic discount factor, which is derived from its first-order conditions with respect to consumption and bond holdings. That is,

$$\Lambda_{t,t+k} = \beta \left(\frac{C_t^o - h_o C_{t-1}^o}{C_{t+k}^o - h_o C_{t+k-1}^o} \right)^\sigma \frac{P_t}{P_{t+k}}$$

Taking expectations of this equation with $k = 1$ gives the Euler equation for optimising consumption with habit persistence. The log-linear representation is given by

$$c_t^o = \frac{h_o}{1+h_o} c_{t-1}^o + \frac{1}{1+h_o} c_{t+1}^o - \frac{1-h_o}{1+h_o} \frac{1}{\sigma} \left(r_t - E_t \pi_{t+1}\right) \tag{19}$$

With habit formation, this equation replaces (2) in the text. Note that they are identical when $h_o = 0$.

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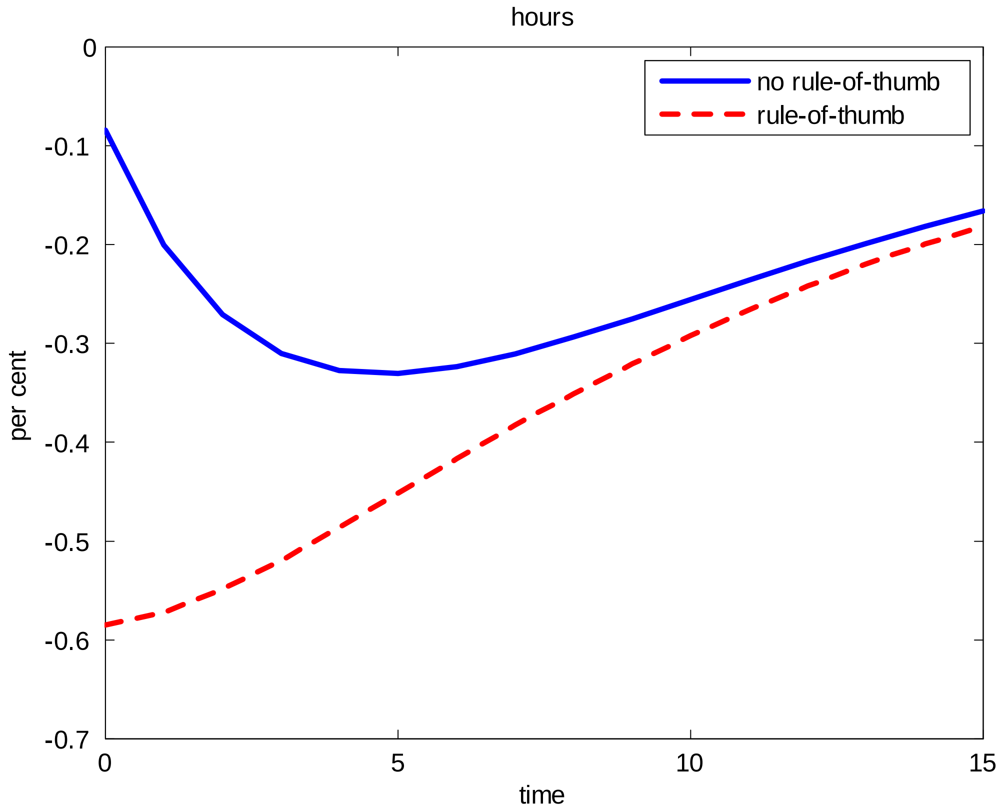

Figure 1: The response of hours to a technology shocks ($\rho_a = 0.9$) in the baseline model (with and without rule-of-thumb consumers).

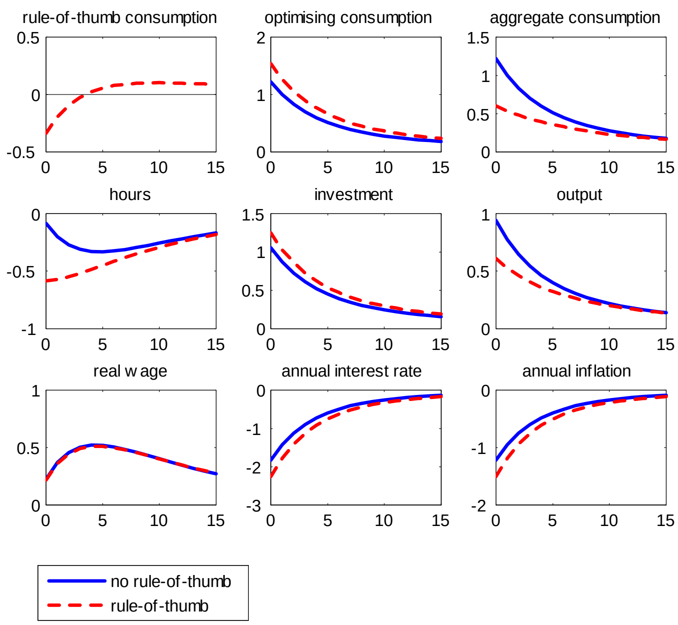

Figure 2: The responses of key variables to a technology shock ($\rho_a = 0.9$) in the baseline model (with and without rule-of-thumb consumers).

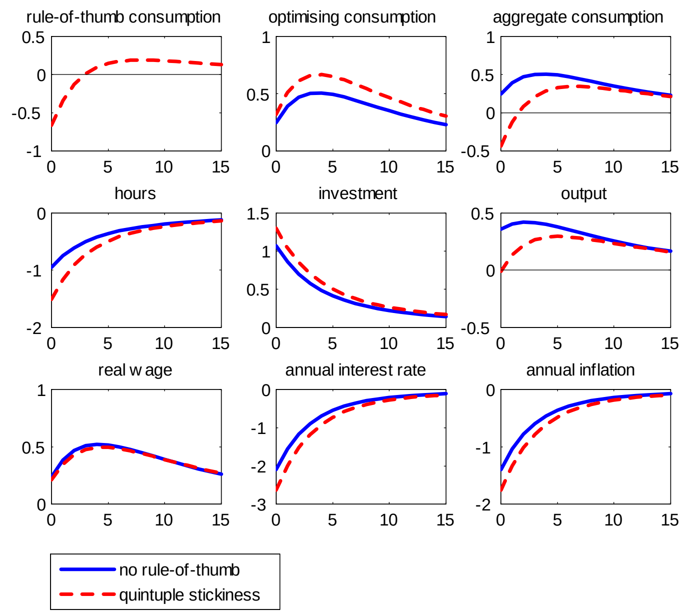

Figure 3: The response of key variables to a technology shock ($\rho_a = 0.9$) in the *quintuple*-sticky model.

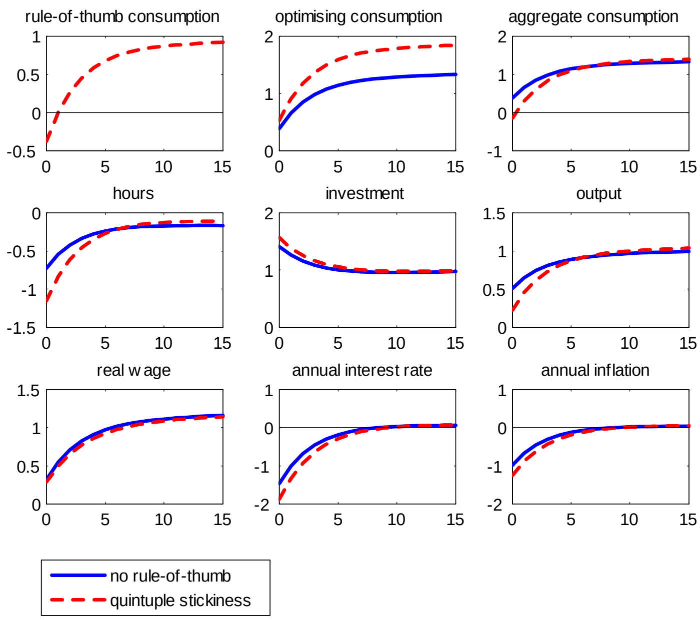

Figure 4: The responses of key variables to a technology shock ($\rho_a = 1$) in the *quintuple*-sticky model.

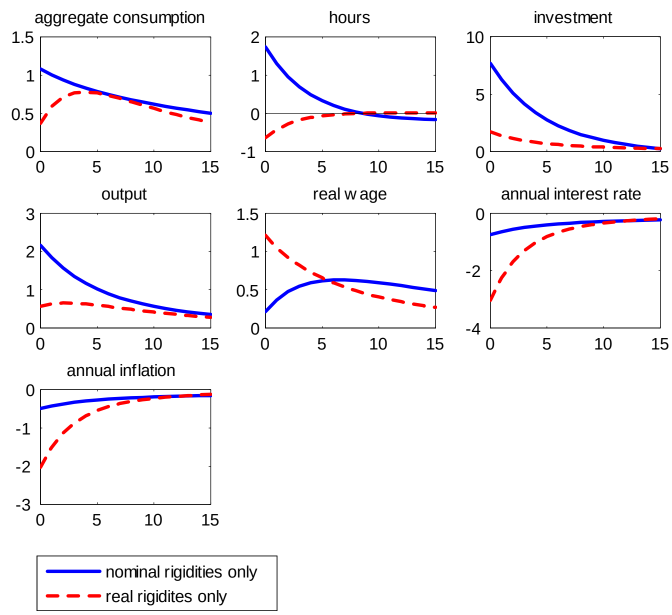

Figure 5: The responses of key variables to a technology shock ($\rho_a = 0.9$) in a version with nominal rigidities only (sticky prices and sticky wages) and in a version with real rigidities only (habit formation and capital adjustment costs).

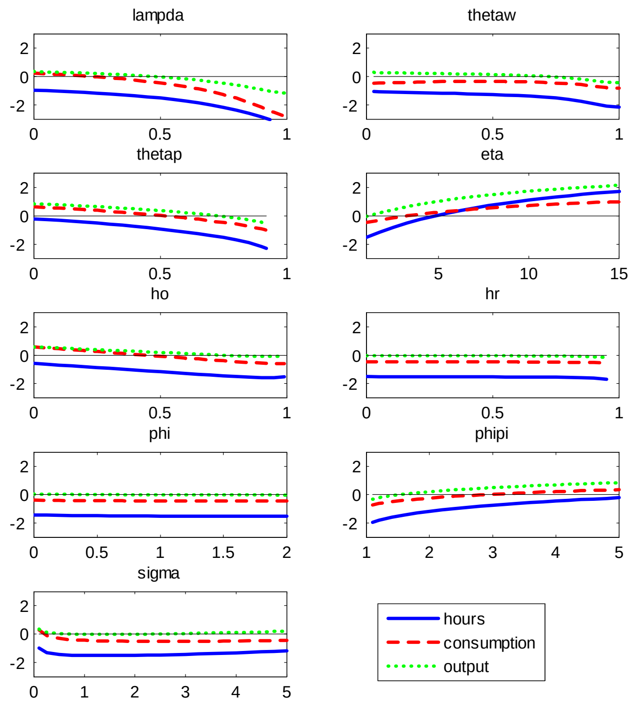

Figure 6: Sensitivity analysis: Impact-responses of hours, consumption and output as a function of parameter values.

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