Rule-of-thumb consumers and the business cycle*

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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. As a consistency exercise, we show that the presence of rule-of-thumb consumers is very helpful in accounting for recent influential empirical evidence on productivity shocks. Rule-of-thumb agents, together with nominal and real rigidities, play an important role in explaining the negative reponse of hours and the zero reponses of output and consumption after a productivity shock.

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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 important in order to generate empirically plausible responses to government spending shocks. Galí, López-Salido and Vallés (2007), henceforth GLV (2007), initiated this literature by introducing so-called rule-of-thumb consumers into an otherwise standard DSGE model with sticky prices. As opposed to intertemporally optimising consumers, rule-of-thumb households consume their current income each period as they are barred from access to financial and capital markets.

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GLV (2007) show that by allowing rule-of-thumb consumers to co-exist with optimising consumers, it is possible to reproduce the well-documented empirical regularity that private consumption increases after a government spending shock. In the model, intertemporally optimising consumers decrease their consumption following a government spending shock because they correctly anticipate a decline in future income as a consequence of taxation. But rule-of-thumb consumers increase their consumption because their current income increases. Under the assumptions of sticky prices, monopolistic competition in the labour market and deficit financing, if a sufficiently large fraction of households behave according to a rule of thumb (30 per cent), aggregate consumption rises.

Many papers have further studied the implications of rule-of-thumb consumers for fiscal policy. Furlanetto (2007) shows that the increase in private consumption following a government spending shock is preserved under sticky wages and different assumptions on labour market structure. Furlanetto and Seneca (2007) show that firm-specific capital and habit persistence can interact with rule-of-thumb behaviour to reduce the fraction of rule-of-thumb households needed to generate a plausible consumption multiplier. Galí, López-Salido and Vallés (2005), Bilbiie (2005), Natvik (2006) and Colciago (2007) check the determinacy properties of the model and show *inter alia* that the Taylor principle seizes to be a necessary condition for uniqueness of the rational expectations equilibrium. In addition, rule-of-thumb consumers have become a standard ingredient in DSGE modelling at policy-making institutions such as the Federal Reserve, the IMF, the ECB, and many other central banks, cf., e.g., Erceg, Guerrieri and Gust (2006). Also, Coenen and Straub (2005) and Forni, Montefiore and Sessa (2007) estimate DSGE models with rule-of-thumb consumers using Bayesian techniques.

As far as we know, the implications of rule-of-thumb behaviour has not been investigated beyond the fiscal policy dimension so far. But rule-of-thumb consumers represent a substantial deviation from the standard optimising framework of DSGE models. In the baseline calibration in GLV (2007), 50 per cent of households have no access to financial and capital markets and so cannot smooth consumption intertemporally. This introduces a considerable market incompleteness with potentially 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 objective of this paper is to test this conjecture. We analyse the impact of rule-of-thumb behaviour on the propagation of productivity shocks in the framework developed by GLV (2007). In our opinion, technology shocks deserve a detailed analysis in this framework. Real business cycle (RBC) theory suggests that technology shocks are the most important driving forces behind business cycle fluctuations, and since the highly influential papers by Kydland and Prescott (1982) and Prescott (1986), the impact of productivity shocks has been one of the most debated topics in the literature. Thus, *a priori* it seems particularly important to study the performance of the model with rule-of-thumb consumers in this dimension. This is even more true since, to our knowledge, the impact of consumer heterogeneity on the propagation of productivity shocks has not been studied so far. We see our exercise as a useful consistency test for the rule-of-thumb theory of consumption.

To facilitate the analysis, we extend the GLV (2007) model in two directions. First, we introduce nominal wage rigidity. Sticky wages have proved to be essential in generating realistic business cycles, cf., e.g., Gali (2007, ch. 6), Furlanetto (2007) and Christiano, Eichenbaum and Evans (2005). Moreover, Liu and Phaneuf (2005) show that sticky wages, in combination with sticky prices, are essential in order to explain the dynamics of hours and wages following a productivity shock. The baseline version of our model is thus characterised by four rigidities, namely price stickiness, wage stickiness, capital stickiness (due to capital adjustment costs), and a financial rigidity barring a fraction of households, the rule-of-thumb consumers, from access to financial and capital markets.

Building on the terminology of McGratten (2004), we therefore refer to this model as the *quadruple*-sticky model. Second, we introduce an additional 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 (2005). Thus, this extention allows us to analyse the role played by many of the frictions studied in the literature and their interaction with rule-of-thumb consumers. We refer to the GLV (2007) model extended with both sticky wages and habit persistence as the *quintuple*-sticky model.

We evaluate the performance of our model by comparing its predictions to the empirical evidence. Galí (1999) and Francis and Ramey (2005) provide such evidence by identifying technology shocks in an estimated vector autoregression (VAR) through long-run restrictions as suggested by Galí (1999). 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. Christiano, Eichenbaum and Vigfusson (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), they obtain a positive response of hours. In recent papers, Fernald (2007) and Canova, Michelacci and López-Salido (2007) show that, once low-frequency movements in hours are taken into account, the negative response of hours is a robust result. 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 view the evidence from the VAR literature to favour the view that hours decrease on impact of a technology shock. Francis and Ramey (2005) also consider other macroeconomic variables. They find that output and private consumption do not respond to the shock on impact, but only after a delay, while the response of investment is insignificant.

An alternative empircal approach is taken by Basu, Fernald and Kimball (2006), henceforth BFK (2006). They use a sophisticated growth accounting framework to clean Solow residuals from 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, BFK (2006) estimate a significant decline in hours on impact of a technology shock, while they find zero responses of output and consumption. In addition, non-residential investment declines significantly in their study.

The response of hours has received much attention in the literature. Since output and hours are strongly positively correlated in the data, a negative responds of hours to a technology shock implies that these shocks cannot be the main driving force behind the business cycle as claimed in the RBC literature. But 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 rule, hours increase as in the baseline RBC model. Francis and Ramey (2005) show that a RBC model augmented with real rigidities (habit persistence and capital adjustment costs) can generate a negative response of hours without relying on nominal rigidities. 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, López-Salido and Vallés (2003) detect significant differences across periods in the Federal Reserve's responses to technology shocks reconciling the results of Galí (1999) and Dotsey (2002).

This paper's first key result is that a model with rule-of-thumb consumers is better at reproducing the empirical responses to a productivity shock because hours are more likely to decline. 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. In our *quadruple*-sticky model with rule-of-thumb consumers, hours decline more: -0.6 per cent. Thus, the model's response coincides with the estimates in BFK (2006) and Francis and Ramey (2005).

The intuition is the following. 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 permanent income and so they increase their consumption. Rule-of-thumb consumers, in contrast, see their current income go down because of the combined effects of sticky prices and wages, and this makes them consume less. In the aggregate, the shock has a less expansionary effect in the model with rule-of-thumb consumers as output and consumption increase less, and hours decline more. In a nutshell, our financial rigidity amplifies the impact of nominal and real rigidities making the transmission mechanism 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. According the results of BFK (2006), the transmission mechanism of technology shocks is very contractionary when considering investment, output and consumption. Surprisingly, this additional evidence on the contractionary effect of productivity shocks 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 BFK (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 are essential 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 zero impact responses of output and consumption as in the empirical evidence. Thus, not only do rule-of-thumb consumers not worsen the performance of the model, they can be very helpful in replicating important empirical regularities. This implies that, in our opinion, rule-of-thumb consumers easily pass the consistency test that served as motivation for this paper. Researchers can safely rely on rule-of-thumb consumers in fiscal policy analyses in the sense that rule-of-thumb behaviour generates reasonable responses to other shocks.[1]

The paper has the following structure. In section 2 we briefly present the *quadruple*-sticky model, and in section 3 we present impulse responses to technology shocks in this version of the model. In section 4 we discuss the *quintuple*-sticky model, and we compare our results to other papers in the literature. 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 GLV (2007), and with sticky wages as in Furlanetto (2007).[2] 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[3].

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

[1] 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 shots down the mechanisms through which rule-of-thumb behaviour may change the propagation of these shocks. Results are available upon request.

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

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

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 income 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 life-time utility. Wages are set by unions that each represent a differentiated type of labour service supplied by households. Wage rigidity is introduced by assuming wage 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.

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 intertemporal elasticity of substitution of labour, 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

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t^o$$

where E_o is an operator representing expectations over all states of the economy conditional on period-0 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, $E_t(\Lambda_{t,t+1} B_{t+1})$. $\Lambda_{t,t+1}$ is the stochastic discount factor. Hence, the gross risk-free interest rate is given by the relation $1 + R_t = (E_t \Lambda_{t,t+1})^{-1}$.

The household's capital evolves according to

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

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:[4]

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

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

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

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

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, and its relation with investment, respectively.

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

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

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

$$c_t^r = \frac{WN}{PC}(w_t + n_t) - \frac{Y}{C} t_t^r$$

where omission of time subscripts indicate steady-state variables. Note that the union membership fee drops out of the first-order approximation. This is because the fee is zero in the steady state, cf. below.

Aggregate variables are given as simple weighted averages:

$$c_t = \lambda c_t^r + (1-\lambda) c_t^o \tag{6}$$

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

and

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

[4] For details on the derivation we refer the reader to GLV (2007). Lowercase variables denote logs of the corresponding uppercase variables.

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,

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

where subscript $t+k|t$ indicate 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 well-known, the optimality conditions from this problem imply the new-Keynesian Phillips curve

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

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 imply the that relative factor inputs satisfy the condition

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

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 a 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 in Rotemberg (1982) and proportional to the aggregate wage bill in the economy, cf. Kim (2000) and Ireland (2003). Though the wage bargaining process is not explictly 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

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

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.[5]

In the special case where $\phi_w = 0$, the model effectively collapses to the model in GLV (2007). Firms do not discriminate between consumer types in its labour demand, and so it follows from the unions' problems that $n_t^r = n_t^o = n_t$.

[5] 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.

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

$$Y_t = C_t + I_t + G$$

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

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

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 GLV (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 $I/Y = 0.18$, $C/Y = 0.62$ and $WN/PC = 0.94$ under the assumption that steady-state price mark-ups are 20 per cent, cf. GLV (2007). However, we deviate from GLV's (2007) calibration in setting $\varphi = 1$ instead of $\varphi = 0.2$, a value we consider to be unrealistically low. GLV (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. This allows us to set a more realistic value. Finally we set $\varepsilon_w = 4$ and $\phi_w = 177$. 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.

3.1 Technology shocks

Figure 2 presents responses to a one standard deviation technology shock $\rho_a = 0.9$. Dashed lines are responses from the *quadruple*-sticky 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 BFK (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 BFK (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 have 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 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 diffently, however. As their horizon is static, neither the increase in permanent income nor the reduction in real interest rates affect 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 affect 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. From figure 2 we see this effect clearly: The model with rule-of-thumb consumers exhibits a larger decline in hours and a smaller increase in aggregate consumption and output than the model without rule-of-thumb behaviour.

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 BFK (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 any affect on the aggregate economy. And finally, capital adjustment costs are needed to dampen investment, an increase in which could otherwise off-set the contractionary effect from the response of rule-of-thumb consumers.

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 new-Keynesian set-up, does not have counterfactual implications for the responses to productivity shocks. On the contrary, we find that the model's transmission mechanism is significantly *improved*.

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 today 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. Moreover, we introduce endogenous monetary policy by letting the model's central bank respond to inflationary 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 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 a decline in hours after a technology shock. But we do not want to evaluate the model in this dimension only. Though the literature has concentrated on the response of hours, the responses to a technology shock of other variables for which we have empirical evidence are important too. Here, we therefore consider the responses of consumption, output and investment.

BFK (2006) provide evidence on the responses of these variables. They find that output and consumption change little on impact of a technology shock, but both increase in the periods following the shock. In contrast, they find that 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 responses in our *quintuple*-sticky model with rule-of-thumb consumers in figure 3 are even too contractionary; hours go down more than one per cent, and aggregate consumption declines slightly. We can undo this excess contraction, however, by modifying the baseline calibration, e.g., by lowering the percentage of rule-of-thumb consumers. Here we keep the parameter values chosen by GLV (2007) to facilitate comparison. An estimated model could deliever more precise guidance on the parameter values needed to replicated the empirical results. Our objective here is simply to show that the *quintuple*-sticky model with rule-of-thumb consumers delivers a very contractionary transmission mechanism.

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, BFK (2006) finds a significantly negative response of this variable after a productivity shocks. Given our analysis, this is puzzling. In the our model, investment increases both with and without rule-of-thumb consumers since optimising households are eager to exploit the favourable improvement in technology. In figure 4, we check that a permanent technology shock delivers the same results as the temporary (but highly persistent) shock considered in figure 3. This is because of the identifying assumption often used in the empirical VAR literature that a technology shock has a permanent effect on labour productivity. We see from figure 4 that responses to a permanent shock are similar. In particular, the impact responses of hours, the real wage, consumption and output are in line with the estimated responses in BFK (2006) and Francis and Ramey (2005).

4.2 Interacting frictions

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 that only has nominal rigidities (solid lines) performs poorly. Consumption, output, hours and investment all increase sharply following the technology shock. In keeping with the results in Francis and Ramey (2005), the model with real rigidities only (dashed lines) is able to reproduce a sizeable decline in hours, but the output, consumption and investment responses are too expansionary compared to those estimated by BFK (2006).[6]

In figure 6, we plot impulse responses for a model whose only friction is capital adjustment costs (solid lines), and for a model with all the frictions considered except capital adjustment costs (dashed lines). That is, the first model has capital adjustment costs, but flexible prices and wages, no habit persistence, and optimising consumers only. The second model has sticky prices and wages, habit persistence, and rule-of-thumb consumers in addition to optimising consumers, but there are no cost of adjusting capital.

From figure 6 we see that capital adjustment costs are needed to obtain a negative response of hours.The model with capital adjustment costs reproduces the decline in hours, whereas the model without capital adjustment cost (but all other frictions considered) has a very expansionary transmission mechanism. Without capital adjustment costs, a technology shock leads to an investment boom that more than offset the contractionary effect from other frictions in the model. But how can investment costs alone explain a reduction in hours following a positive technology shock?

The intuition is the following. A technology shock leads to an increase in the permanent income of consumers. Through the income effect, this means

[6] In section 3 we argued on the basis of the model without habit persistence that rule-of-thumb behaviour was essential in order to explain a sizeable decline in hours. This illustrates the potential for habit persistence and rule-of-thumb behaviour to induce observationally equivalent responses in aggregate variables through implications for aggregate consumption, cf. Furlanetto and Seneca (2007).

that workers would like to work less. Therefore, unions set a higher wage so as to induce a lower labour demand. In addition, consumers would like to take advantage of the new technology by investing heavily in capital goods. But capital adjustment costs prevents them from doing so. This means that the increase in aggregate demand from consumption and investment spending is not high enough to generate an increase in labour demand that may offset the effects of the unions' wage demands on employment. Hence, hours worked decline in equilibrium.

This latter result that capital investment costs are key when explaining the response of hours has not been emphasised in the literature. Francis and Ramey (2005) show that hours decline in a model with real rigidities, but they do not disentangle the different roles played by habit persistence and capital adjustment costs. Indeed, they suggest that capital adjustment costs need to interact with habit formation in order to generate the negative response in hours. Moreover, monetary policy is exogenous in their model. Francis, Owyang and Theodorou (2005) show that capital adjustment costs are important, but they do not show the interactions with the other frictions, and they suggest that capital adjustment costs must interact with sticky prices.

Finally, we note that the *quintuple*-sticky model does not shed further light on the investment response puzzle. 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. BFK (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 GLV (2003) supports this claim.

In sum, our study of the *quintuple*-sticky model gives the following results.

- The *quintuple*-sticky model (a model with both real and nominal rigidites as well as a financial friction) features a contractionary transmission mechanism that can reproduce responses of hours, real wages, consumption and output in line with the empirical evidence.

- A model with real rigidities alone can explain a sizeable 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.

- Capital adjustment cost is the key friction needed to reproduce anegative response of hours.

- Investment increases in all versions of the model.

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 decline in hours worked after a positive productivity shocks as suggested by the empirical evidence by Gali (1999), Francis and Ramey (2005) and BFK (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. We show that the key friction needed to reproduce the negative response of hours found in empirical studies is capital adjustment costs. Nominal rigidities alone cannot explain this fact, according to our findings.

We leave for future research to provide a better understanding of investment dynamics; the empirical facts concerning investment's response to technology shocks cannot be explained by the class of models considered.

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 models becomes less realistic in other dimensions. Indeed, the analysis suggest that rule-of-thumb behaviour may play an important role in business cycle dynamics. An important topic for future empirical research is to investigate the validity of this suggestion.

A Appendix

The first-order condition to the union's problem becomes

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

Since the demand for union z's type of labour service is given by

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

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

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

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

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

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

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

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

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

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

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

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

and

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

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,

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

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

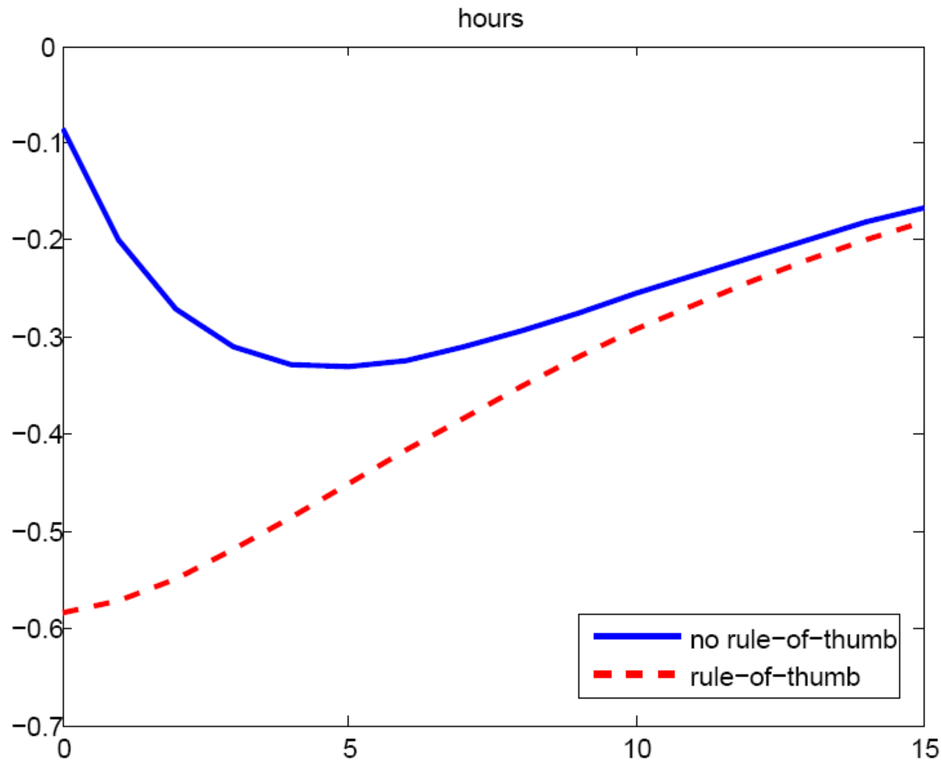
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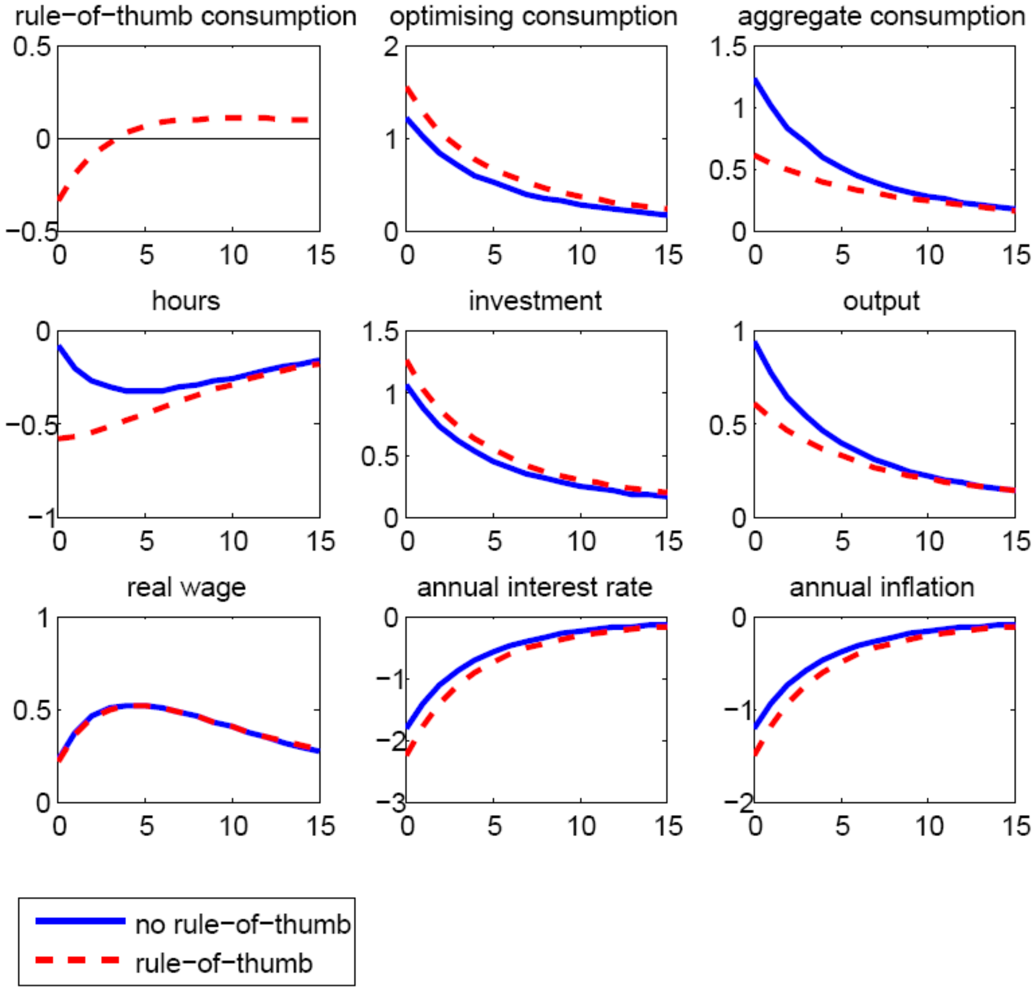
Figure 2



rule−of−thumb consumption
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aggregate consumption
hours
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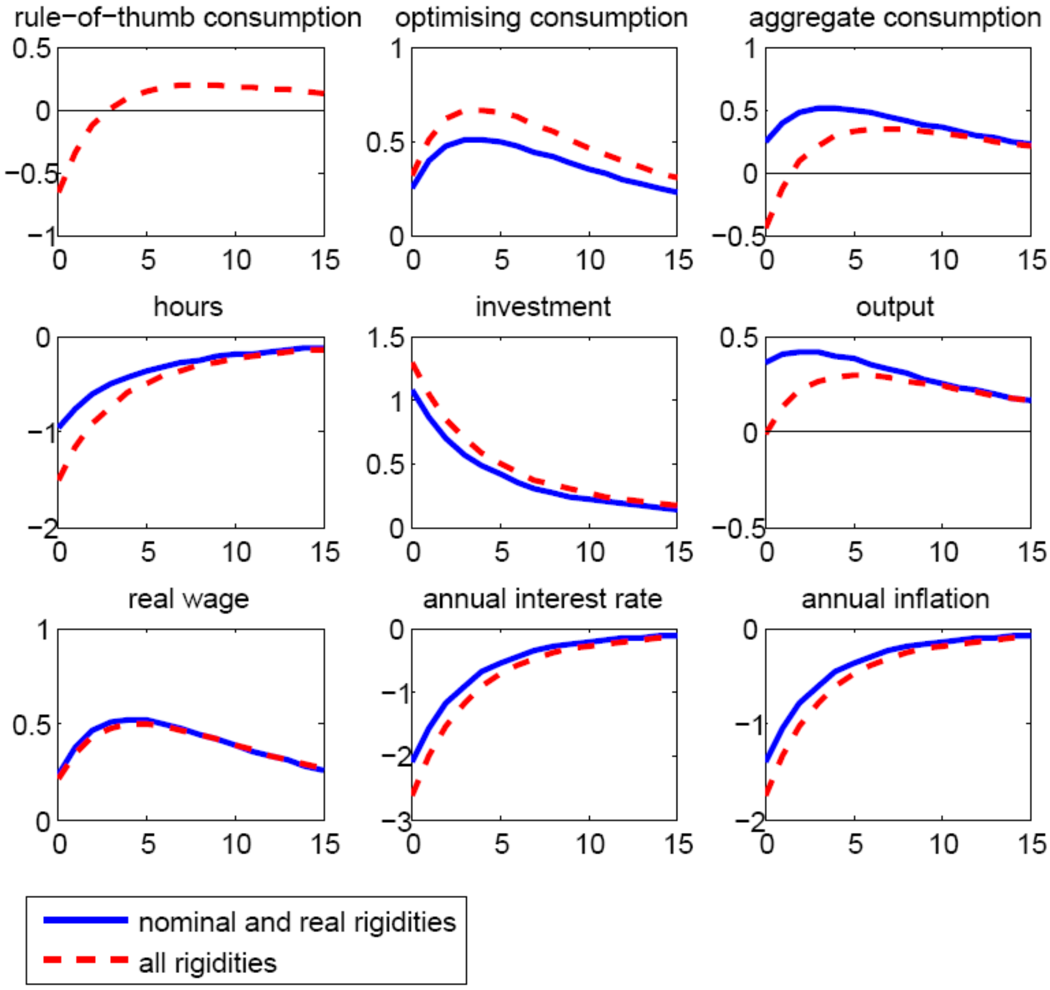
output
real wage
annual interest rate
annual inflation
no rule−of−thumb
rule−of−thumb

Figure 3


rule−of−thumb consumption
optimising consumption
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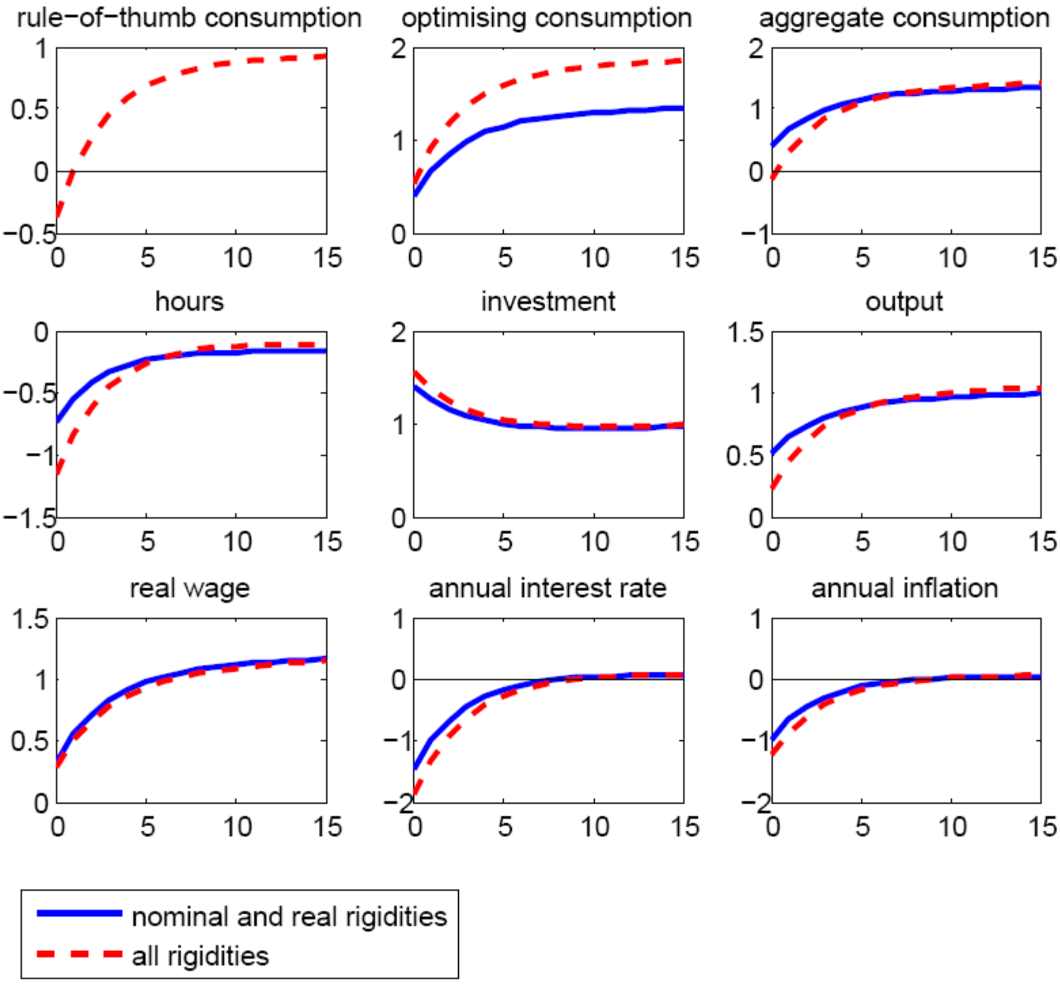
real wage
annual interest rate
annual inflation
nominal and real rigidities
all rigidities

Figure 4



rule−of−thumb consumption
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Figure 5

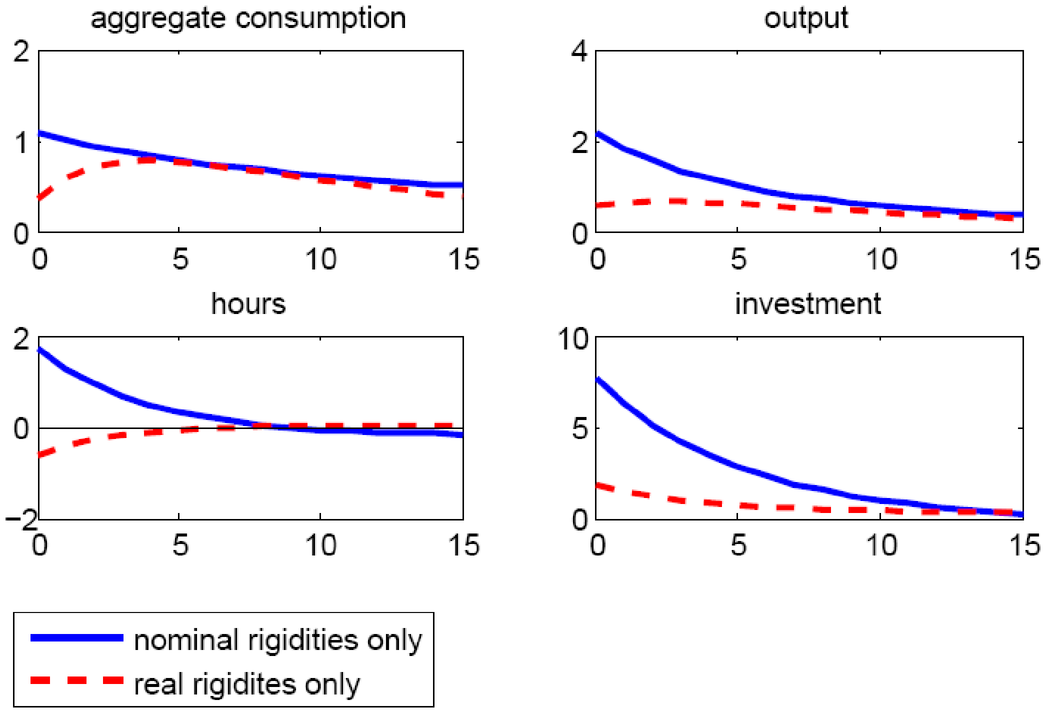

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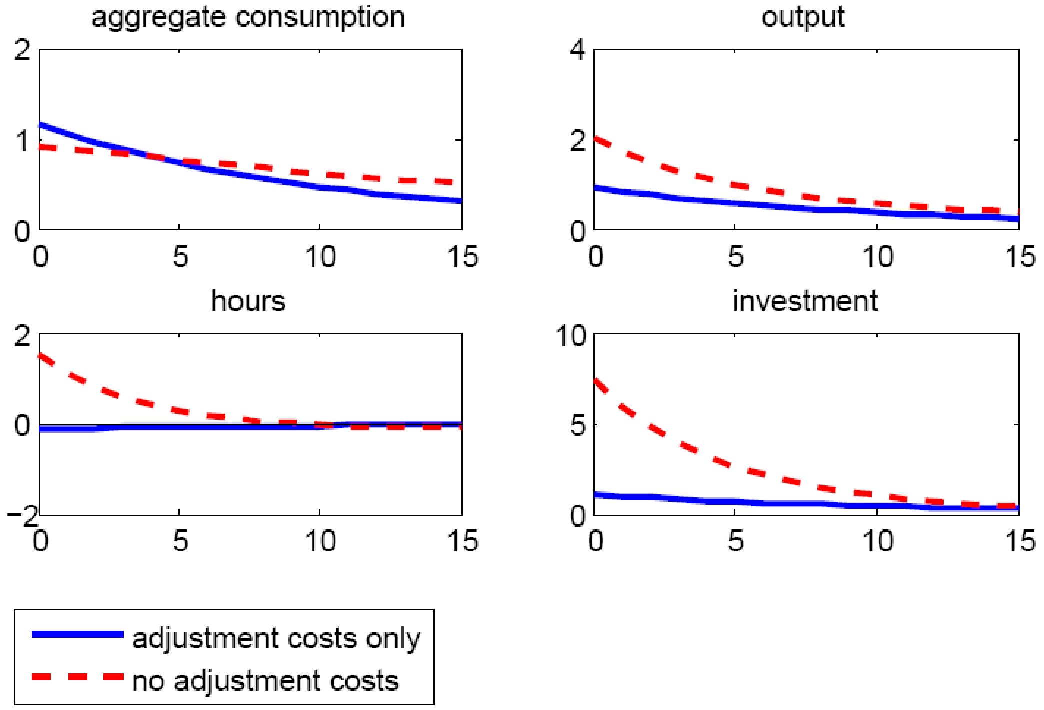
Figure 6



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adjustment costs only
no adjustment costs