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Francesco Furlanetto* Martin Seneca†

*Norges Bank, francesco.furlanetto@norges-bank.no

†Central Bank of Iceland, martinweb1@seneca.dk

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Fiscal Shocks and Real Rigidities*

Francesco Furlanetto and Martin Seneca

Abstract

In this paper we show that results on the effects of fiscal shocks in Galí, López-Salido and Vallés (2007) rely on a high degree of price stickiness and a large percentage of financially constrained agents. Real rigidities in the form of habit persistence, fixed firm-specific capital and Kimball demand curves interact in interesting ways with nominal and financial rigidities and allow us to reproduce the same consumption multiplier as Galí et al. (2007) under only two and a half quarters of price stickiness, instead of four, and only 30 per cent of constrained agents instead of 50 per cent. Therefore, real rigidities are useful in the study of fiscal shocks in addition to monetary and productivity shocks as has been shown in the previous literature, though rule-of-thumb consumption remains too crude a mechanism for accounting for the hump-shaped response of consumption found in the data.

KEYWORDS: rule-of-thumb consumers, fiscal shocks, nominal rigidities, real rigidities, firm-specific capital, habit persistence, Kimball demand curves

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1 Introduction

In this paper, we analyse the response of private consumption to a government spending shock in a New Keynesian DSGE model with nominal and real rigidities as well as credit-constrained households. The interaction of these rigidities allows us to reproduce a positive response of private consumption to a government spending shock for more reasonable parameter values than those previously used in the literature. By adding real rigidities (in the form of habit persistence, fixed firm-specific capital and non-constant elasticities of demand) to the model by Galí et al. (2007), we are able to generate the same increase in consumption as in the original model with a share of credit-constrained households given by 0.3 (instead of 0.5) and an expected duration of prices set at 2.5 quarters (instead of 4). Thus, we find that real rigidities are useful not only in accounting for the economy's responses to monetary policy and productivity shocks as has been emphasised in the existing literature, but also in accounting for responses to fiscal policy shocks.[1]

A number of recent empirical papers suggest that private consumption does indeed increase following a positive shock to government spending. Under different identifying assumptions in structural VAR analyses of quarterly US data, Blanchard and Perotti (2002), Fatas and Mihov (2002), Galí et al. (2007), Mountford and Uhlig (2005), and Perotti (2005, 2007) all estimate the response of consumption to be significantly positive. The exact size of the response differs somewhat across specifications. However, in a comprehensive comparison of the approaches used in these papers, Caldara and Kamps (2008) show that the identification strategy does not affect the results substantially over the period 1955-2006; a one dollar government spending shock increases private consumption by around 0.2 dollars on impact of the shock, while peaking at around 0.9 between 10 and 15 quarters after the shock independent of the identification strategy used.

In contrast to theses studies, Ramey and Shapiro (1998) estimate the response of private consumption to be negative using the so-called narrative approach, which is based on episodes of large increases in military spending. However, Perotti (2007) argues that this result is driven by responses to spending on the Korean war, which was financed by a large increase in taxes, unlike the other military build-ups considered. Perotti (2007) and Caldara and Kamps (2008) show that once the Korean war is excluded from the sample, the narrative approach delivers results that are similar to those of the structural

[1]See e.g. Altig et al. (2005), Christiano et al. (2005), Smets and Wouters (2003 and 2007) and Woodford (2003). For specific analysis on productivity shocks, see Francis and Ramey (2005) and Furlanetto and Seneca (2007).

VAR analyses. Ramey (2008) defends the narrative approach and argues that the government spending shocks identified in the structural VAR literature are mostly anticipated shocks. Therefore, she argues, the approach misses an initial decline in consumption. Hence, while we take the empirical evidence to suggest that private consumption increases following a positive shock to government spending, we acknowledge that the question is still to be finally settled in the literature.

The empirically observed increase in private consumption following a positive shock to government spending is in stark contrast with the predictions of the basic real business cycle (RBC) model. In the RBC model of Baxter and King (1995), private consumption declines as a consequence of Ricardian equivalence. In contrast, in the New Keynesian model by Galí et al. (2007), deviations from Ricardian equivalence can generate a positive response to consumption in an otherwise standard dynamic stochastic general equilibrium (DSGE) framework. In the model, optimising consumers decrease their consumption because they correctly anticipate a decline in future income as a consequence of taxation. But rule-of-thumb consumers, who have no access to financial markets and therefore simply consume their current disposable income each period, increase their consumption because their current income increases.[2] Under the necessary auxiliary 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, aggregate consumption rises.

In this paper, we show that the result in Galí et al. (2007) is fragile along two dimensions. It relies on both a high degree of price rigidity and a large deviation from Ricardian equivalence. In the baseline calibration in Galí et al. (2007), the expected duration of prices is set at one year, and half the consumers in the economy choose how much to consume by following a simple rule of thumb. Recent microeconomic evidence, however, points to two or three quarters of expected price duration, e.g. Bils and Klenow (2004) and Nakamura and Steinsson (2007), and several studies arrive at estimates of the percentage of rule-of-thumb consumers that are much lower than the 50 per cent used by Galí et al. (2007). For instance, 16 per cent of the households interviewed in the latest Survey of Consumer Finances (SCF) report that their

[2] The idea that a rule-of-thumb consumers may co-exist with optimising households was first put forward in the empirical consumption literature as an alternative to the permanent income hypothesis, see in particular Hall (1978) and Campbell and Mankiw (1989). We emphasise the interpretation that some households follow a rule of thumb because a financial friction bars them from participating in financial and capital markets. Alternatively, rule-of-thumb consumers may choose not to do so because of myopia or extreme impatience.

spending is usually about the same as their income, while remaining households either save or accumulate debt, cf. Bucks et al. (2006). Estimates using aggregate data are usually somewhat higher than indicated by the survey evidence. This is because estimations are generally based on the assumption that heterogeneity across agents can be captured by the assumption that households are either very sophisticated forward-looking optimisers (though their habits are possibly persistent) or rule-of-thumb consumers. Consumption-saving behaviour in-between the two extremes is therefore likely to show up in a higher estimate of the share of rule-of-thumb households in analyses of aggregate behaviour. Hence, Campbell and Mankiw (1991) arrive at 35 per cent, while Fuhrer (2000) puts the estimate at 26 per cent using full-information maximum likelihood and 29 per cent using the generalised method of moments.

The values of these parameters are crucial in the Galí et al. (2007) model without real rigidities. Once they are lowered to more realistic values given the empirical evidence - say, 2.5 quarters of price stickiness and 30 per cent of constrained agents as in our benchmark calibration[3] - the main result that the presence of rule-of-thumb consumers can generate a positive response of consumption following a government spending shock is lost.

The main objective of this paper is to reconcile the evidence on these structural characteristics of the economy with a positive and sizeable consumption multiplier following a government spending shock. We show that this can be done by adding a number of what we consider to be realistic features to the model developed by Galí et al. (2007) to lower its dependence on price stickiness and households that do not take part in financial markets so as to smooth consumption. The features we consider are real rigidities in the form of habit persistence in consumption, non-constant elasticities of demand, and fixed firm-specific capital.[4] As noted above, each of these rigidities has proven to be very useful in DSGE analyses in explaining empirical regularities of

[3]We set the fraction of rule-of-thumb consumers to the intermediate value of 0.3 given the empirical evidence just cited. This value is also close to the prior values used by López-Salido and Rabanal (2008) and Bilbiie and Straub (2006) in Bayesian estimation of this fraction. As posterior distributions in both analyses point to even lower values, we provide a sensitivity analysis below.

[4]We refer to all these three features as real rigidies to separate them conceptionally from nominal rigidities that act as direct impediments to the adjustment of nominal variables, and from a financial rigidity represented by rule-of-thumb consumers. Hence, our definition includes both the rigidities that work as direct impediments to the adjustment of real variables (habit persistence), and the 'real rigidities' of Ball and Romer (1990), the presence of which characterises an economy with strategic complementarity in price setting (firm-specific capital and Kimball demand curves), cf. the discussion in Woodford (2003, ch. 3).

the transmission of other shocks, especially monetary policy and productivity shocks. But their implications for the propagation of fiscal shocks have not been thoroughly analysed so far. This, in itself, provides a second motivation for this paper.

We note at the outset that our model - as the original model by Galí et al. (2007) - is unable to replicate the hump-shaped consumption response that is present in the data. Habit persistence does not work to generate a hump-shaped consumption response as speculated by Galí et al. (2007). This is because habit persistence among optimising consumers does not affect the consumption profile of constrained agents, who remain indifferent or unable to respond to future as well as past consumption prospects. Hence, while a reasonable level of rule-of-thumb consumption may help explain a positive response of consumption following a government spending shock in a model with nominal *and* real rigidities, the mechanism is too crude to adequately account for the timing of the dynamic adjustment observed in the data.

The paper is organised as follows. In section 2, we present the model. In section 3 we present the results and provide a discussion. Section 4 gives a few concluding remarks.

2 The model

The model is a standard New Keynesian dynamic stochastic general equilibrium model augmented with habit persistence in consumption, Kimball (1995) demand curves and rule-of-thumb consumers. Except for the presence of real rigidities, the model is identical to Galí et al. (2007). 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 and issuing bonds to finance its expenditures. 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 income each period. The remaining fraction $1 - \lambda$ of households are optimisers - or 'savers' - that have access to financial markets. Hence, they choose plans for consumption and bond holdings to maximise lifetime utility.

Consumers are assumed to form habits in consumption. That is, the utility a household obtains from a given level of consumption in a given period depends on the level of consumption in that period relative to the level of consumption in the previous period.[5] In our model, habit persistence is important because it smooths the negative response of optimising households to a government spending shock. Hence, a smaller fraction of rule-of-thumb consumers is needed to generate a plausible response of aggregate consumption.

Wages are set by unions each representing a differentiated type of labour service supplied by households. Wages are assumed to be flexible. That is, each union sets a new wage for its members each period to maximise an average of their utilities taking the effect of this wage on the members' budget constraints into account.

Each firm produces one of the differentiated intermediate goods. It does so by combining capital with a homogenous labour input constructed as a Dixit-Stiglitz 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.

The elasticity of the demand faced by the firm depends on the level of output produced as in Kimball (1995). This represents a modification of the formalisation of monopolistic competition by Dixit and Stiglitz (1977) that has become standard in macroeconomics following the seminal paper by Blanchard and Kiyotaki (1987). The relative demand for an individual good is still decreasing in the relative price, but the elasticity – and hence the desired mark-up over marginal costs of the price-setting firm that produces it – now depend on its relative output. This induces a potential source of strategic complementarity in price setting in the model as discussed by Kimball (1995) and Woodford (2003, ch. 3). If the elasticity of demand falls with relative output, for instance, a firm that reduces its price will moderate its price reduction because the increase in demand it induces increases the desired mark-up. In this case, the firm is more reluctant to change prices away from the level charged by other firms in the economy that may not be changing their prices in any given period. In this way, the Kimball demand specification amplifies the effect of any nominal price rigidity that prevents some firms from adjusting prices.

[5] The idea that habits may influence households' consumption behaviour grew out of the attempts in the mid-20th century empirical demand theory to explain the importance of lagged dependent variables in estimated demand functions, see e.g. Brown (1952), or the discussions of this literature in Deaton and Muellbauer (1980) and Deaton (1992). More recently, habit formation has been introduced into policy-oriented general equilibrium models following the specification in the asset pricing model by Abel (1990).

For our purposes, the implications of Kimball demand are important because they make it possible to obtain dynamics of key macroeconomic variables that are similar to the ones in a model with constant elasticity, but with a lower degree of nominal price stickiness as emphasised by Eichenbaum and Fisher (2007) and Levin et al. (2007). Moreover, by lowering the inflation response to a given change in marginal costs, Kimball demand functions work to dampen the monetary policy response. A lower increase in the interest rate following a positive government spending shock pushes up optimising consumption, allowing us to lower the percentage of rule-of-thumb consumers in the model (for a given consumption multiplier). This effect has not been emphasised in the literature so far.

We consider two alternative assumptions concerning the structure of the capital market. Under the first assumption, the economy's capital stock is owned by the optimising households. In this case, firms rent the capital they employ in production in a common rental market, and capital can be reallocated across firms instantaneously. We allow for endogenous accumulation of capital under this assumption by letting households choose how much to invest in new capital each period. But we also assume that it is costly to adjust the capital stock. Consequently, the aggregate stock of capital is fixed in the limiting case where the capital adjustment cost goes to infinity. Rule-of-thumb consumers do not take part in the capital market.

Under the second assumption, the capital stock is owned by firms, and capital cannot be reallocated across them to equalise marginal costs. That is, capital is specific to individual firms. As argued, for instance, by Danthine and Donaldson (2002), the firm-specific capital assumption, which is a relatively recent addition to the DSGE literature, is probably the more appealing one in terms of realism.[6] For our purposes, the important implication of firm-specific capital is that it increases the strategic complementarity in price setting as described by Sveen and Weinke (2005) and Woodford (2005). For simplicity, we follow Coenen et al. (2007) by abstracting from the endogenous accumulation of firm-specific capital.[7] Instead, we assume that each firm is endowed with a fixed level of the capital good as in Sbordone (2002), resulting in a production process with decreasing returns to labour. With this specification, we retain

[6] Firm-specific capital in DSGE models was pioneered by Christiano (2005), Sveen and Weinke (2005) and Woodford (2005).

[7] Similarly, some authors abstract from the endogenous capital accumulation process under the rental market assumption, e.g. Erceg et al. (2000).

the important implication of firm-specific capital that firms cannot reallocate capital instantaneously across firms.[8]

To encompass these two alternative assumptions on the structure of the capital market in the model, we define a dummy variable ι taking the value 1 under the rental market assumption and 0 when capital is firm-specific[9], i.e.

$$\iota = \begin{cases} 1 & \text{if capital is owned by households} \\ 0 & \text{if capital is owned by firms} \end{cases}$$

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

2.1 Households

The instantaneous utility function of a household is given by

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

where $i \in \{o, r\}$ denotes the type of household – optimising or rule-of-thumb – 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 in the 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

[8] Alternative mechanisms to increase the strategic complementarity in price setting include search frictions in the labour market (Sveen and Weinke, 2007; Thomas, 2008), intermediate inputs to production (Basu, 1995), and factor specificity in general, cf. the discussion in Woodford (2003). Open economy features, like perfect mobility of labour (immigration effects), capital and goods can also affect inflation dynamics, cf. Razin and Binyamini (2007). We choose the ones we consider to be the most widely accepted in the literature but note that the exact source of strategic complementarity is not essential for our results. However, it may have implications for the derivation of optimal monetary policy, cf. Levin et al. (2008).

[9] Nothing, in principle, prevents this variable from taking intermediate values. This would correspond to an economy in which a share of the capital stock is owned by households and rented to firms, while the remaining share is firm-specific. We do not pursue this possibility here, though few things would change in the specification of the model.

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.

An optimising household maximises expected lifetime utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t^o \tag{2}$$

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):

$$P_t C_t^o + E_t\left(\Lambda_{t,t+1} B_{t+1}\right) = W_t N_t^o + B_t - P_t T_t^o + \iota\left(R_t^k K_t^o - P_t I_t^o\right) \tag{3}$$

where W_t is the nominal wage, P_t is the aggregate price index and T_t^o is the real lump-sum tax paid by optimising consumers. The left-hand side gives the allocation of resourses to consumption and a portfolio of bonds, $E_t\left(\Lambda_{t,t+1} B_{t+1}\right)$, where $\Lambda_{t,t+1}$ is the stochastic discount factor so that the risk-free interest rate is given by the relation $1 + R_t = \left(E_t \Lambda_{t,t+1}\right)^{-1}$. The right-hand side gives available resources as the sum of labour income, $W_t N_t^o$, initial financial wealth, B_t, less nominal lump-sum taxes paid to the government, $P_t T_t^o$. Finally, under the assumption that the economy's capital stock is owned by households, the household receives rent for its capital, $R_t^k K_t^o$, where R_t^k is the rental rate of the capital it owns, K_t^o, and allocates resources to investment, $P_t I_t^o$. Under this assumption, the household's capital evolves according to

$$K_{t+1}^o = (1-\delta) K_t^o + \phi\left(\frac{I_t^o}{K_t^o}\right) K_t^o \tag{4}$$

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 and bond holdings, gives rise to a modified version of the well-known Euler equation which we state in log-linear form[10]:

$$c_t^o = \frac{1}{1+h_o} c_{t-1}^o + \frac{1}{1+h_o} E_t c_{t+1}^o - \frac{1-h_o}{1+h_o} \frac{1}{\sigma} \left(r_t - E_t \pi_{t+1}\right) \tag{5}$$

where $\pi_t = p_t - p_{t-1}$ is price inflation. Because of habit formation in consumption, the Euler equation now contains a term in lagged consumption. Note

[10]In general, lower case variables denote log-deviations from corresponding uppercase variables. Omission of time subscripts indicates steady-state variables.

that this equation reduces to the standard Euler equation for $h_o = 0$. For $\iota = 0$, i.e. under the assumption that firms own the capital stock, this is the only first-order condition for optimising consumers. For $\iota = 1$, i.e. with a rental market for capital, the optimising household also chooses investment. As shown by Galí et al. (2007), the first-order conditions to this problem represent the dynamics of Tobin's q and its relation to investment, and their log-linear forms are given by

$$q_t = -\left(r_t - E_t\left[\pi_{t+1}\right]\right) + \left[1-\beta\left(1-\delta\right)\right] E_t\left[r^k_{t+1} - p_t\right] + \beta E_t\left[q_{t+1}\right] \tag{6}$$

$$i_t - k_t = \eta q_t \tag{7}$$

where $\eta = -1/\left(\phi''\left(\delta\right)\delta\right)$.[11]

A rule-of-thumb household does not take part in financial or capital markets, and thus faces the following simple budget constraint regardless of the assumption on the ownership of capital:

$$P_t C^r_t = W_t N^r_t - P_t T^r_t \tag{8}$$

Here, C^r_t is the household's real consumption at time t, and N^r_t is the hours worked by the household in period t. 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

$$c^r_t = \frac{WN}{PC}\left(w_t + n_t\right) - \frac{Y}{C} t^r_t \tag{9}$$

where omission of time subscripts indicates steady-state variables.[12]

Aggregate variables are given as simple weighted averages:

$$c_t = \lambda c^r_t + \left(1-\lambda\right) c^o_t \tag{10}$$

$$n_t = \lambda n^r_t + \left(1-\lambda\right) n^o_t \tag{11}$$

and

$$t_t = \lambda t^r_t + \left(1-\lambda\right) t^o_t \tag{12}$$

[11] Note that i_t and k_t are the log-deviations from corresponding steady-state values of aggregate investment and capital, respectively, defined as $K_t = \left(1-\lambda\right) K^o_t$ and $I_t = \left(1-\lambda\right) I^o_t$.

[12] We maintain the assumption that consumption is equalised across agents in the steady state to facilitate comparability with Galí et al. (2007). For an alternative approach, see Natvik (2008).

2.2 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-Stiglitz aggregate of the labour services provided by the unions in the economy. Hence, the labour demand for a union's labour services is given by

$$N_t(z) = \left(\frac{W_t(z)}{W_t}\right)^{-\varepsilon_w} N_t \tag{13}$$

where $W_t(z)$ is the wage set by the union, and ε_w is the elasticity of labour demand.

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,

$$\max_{W_t(z)} E_t \sum_{k=0}^{\infty} \beta^{t+k} \left[\lambda U^r_{t+k} + (1-\lambda) U^o_{t+k}\right] \tag{14}$$

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.

The first-order condition can be expressed in the form of Galí et al. (2007):

$$\left[\frac{\lambda}{MRS^r_t} + \frac{1-\lambda}{MRS^o_t}\right]\frac{W_t}{P_t} = \frac{\varepsilon_w}{\varepsilon_{w-1}} \tag{15}$$

where, now, the marginal rate of substitution is given by $MRS^i_t = (C^i_t - h_i C^i_t)^{\sigma} N^{\varphi}_t$ for $i \in \{o, r\}$ because of habit formation in consumption. As shown by Furlanetto and Seneca (2007), log-linearising this expression gives

$$w_t - p_t = \chi_r \left(c^r_t - h_r c^r_{t-1}\right) + \chi_o \left(c^o_t - h_o c^o_{t-1}\right) + \varphi n_t \tag{16}$$

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

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

2.3 Goods demand

The economy has a continuum of firms $j \in [0,1]$, each of which produces a differentiated product, $Y_t(j)$. The final good used in private and public consumption is an index of this continuum of intermediate goods. Following Kimball (1995) it is defined implicitly by the relationship

$$\int_0^1 \mathcal{G}(X_t(j))\, dj = 1 \tag{17}$$

where $X_t(j) = Y_t(j)/Y_t$ is relative demand, and $\mathcal{G}(.)$ is a function satisfying $\mathcal{G}(1) = 1$, $\mathcal{G}' > 0$ and $\mathcal{G}'' < 0$.

For a given level of consumption and investment, and for given prices, $P_t(j)$, expenditure minimisation leads to the following demand for firm j's product

$$X_t(j) = \tilde{\mathcal{G}}\left(\frac{P_t(j)\, Y_t}{\upsilon_t}\right) \tag{18}$$

where $\tilde{\mathcal{G}}(.)$ is the inverse function of $\mathcal{G}'(.)$ and υ_t is the Lagrange multiplier from the minimisation problem. If we define the price deflator P_t implicitly by

$$P_t Y_t = \int_0^1 P_t(j)\, Y_t(j)\, dj \tag{19}$$

we have

$$\upsilon_t = P_t Y_t \left(\int_0^1 \mathcal{G}'(X_t(j))\, X_t(j)\, dj\right)^{-1} \tag{20}$$

Note that the assumption that $\mathcal{G}'' < 0$ implies that this demand function is downward-sloping. It follows that the price elasticity of demand is given by

$$\xi(X_t(j)) = -\frac{\mathcal{G}'(X_t(j))}{\mathcal{G}''(X_t(j))\, X_t(j)} \tag{21}$$

In log-linear terms, the demand function becomes

$$y_t(j) = -\bar{\xi}\left(p_t(j) - p_t\right) + y_t \tag{22}$$

where $\bar{\xi} = \xi(1)$.

In the special case where

$$\mathcal{G}\left(X_t(j)\right) = \left(X_t(j)\right)^{\frac{\epsilon-1}{\epsilon}} \tag{23}$$

(17) reduces to the more common Dixit-Stiglitz aggregator, which leads to a constant elasticity of substitution since, in this case, $\xi\left(X_t(j)\right) = \bar{\xi}$ for all $X_t(j)$. As is well-known, this leads to a constant desired mark-up of price-setting firms given by $\mu_p = \bar{\xi}/\left(\bar{\xi}-1\right)$. In the general Kimball specification, we allow the demand elasticity and hence the desired mark-up to vary with the level of output. For future reference define

$$\epsilon\left(X_t(j)\right) = \frac{\partial \xi\left(X_t(j)\right)}{\partial P_t(j)} \frac{P_t(j)}{\xi\left(X_t(j)\right)} \tag{24}$$

This is the own price elasticity of the elasticity of demand. In the steady state we have $\epsilon(1) = \bar{\epsilon}$. In the analysis, we employ the case where $\bar{\epsilon} > 0$, i.e., the case where the elasticity of demand is increasing in the price set by the firm, or equivalently decreasing in its relative output. This is known to increase the strategic complementarity in price setting as discussed in section 2.

2.4 Firms

Firm j produces according to the technology

$$Y_t(j) = \tilde{K}_t(j)^{\alpha} N_t(j)^{1-\alpha} \tag{25}$$

where $\tilde{K}(j)$ the capital used as input by firm j, $N_t(j)$ is the labour employed by the firm, and $0 < \alpha < 1$. When the capital is owned by the firms, we assume that all firms have identical endowments of capital and we normalise this level to 1. Denoting the household-owned capital employed in production by firm j by $K_t(j)$, we have in general that $\tilde{K}_t(j) = \left(K_t(j)\right)^{\iota}$. Note that real marginal costs are given by

$$MC_t(j) = \frac{W_t/P_t}{(1-\alpha)\left(\tilde{K}_t(j)/N_t(j)\right)^{\alpha}} \tag{26}$$

When firms rent capital from households, i.e. when $\iota = 1$, cost minimisation implies that firm j will choose factor inputs such that

$$\frac{W_t}{R_t^k} = \frac{1-\alpha}{\alpha} \frac{K_t(j)}{N_t(j)} \tag{27}$$

Since all firms have to pay the same wage for the labour they employ, and the same rental rate for the capital they rent, it follows that marginal costs are equalised across firms under this assumption. In contrast, when $\iota = 0$ and capital is firm-specific, marginal costs will generally be different across firms.

We now turn to the firms' price-setting decisions. Each firm is allowed to set a new price, P_t^*, with a fixed probability $(1-\theta)$ as in Calvo (1983). This implies that the expected duration of prices is given by $(1-\theta)^{-1}$.The firm's decision is made to maximise the value of the firm to its owners, the optimising households, given by

$$\sum_{k=0}^{\infty} E_t \left\{ \Lambda_{t,t+k} \left[P_t^* Y_{t+k}(j) - \Psi\left(Y_{t+k}(j)\right) \right] \right\} \tag{28}$$

where $\Psi(.)$ is the cost function, subject to its production function (25) and to the demand for its product given by (18).[13]

The following first-order condition represents the price-setting equation:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k}(j) \left[P_t^* \left(1 - \xi\left(X_{t+k}(j)\right)\right)\right] \right\}$$
$$= \sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k}(j) \left[\xi\left(X_{t+k}(j)\right) P_{t+k} MC_{t+k}(j) \right] \right\} \tag{29}$$

where $MC_t(j)$ is firm j's real marginal cost given by (26).

From the log-linearisation of (29) we may derive the following New Keynesian Phillips curve for price inflation

$$\pi_t = \beta E_t \pi_{t+1} + \kappa mc_t \tag{30}$$

where the slope parameter κ is given by

$$\kappa = \frac{(1-\beta\theta)(1-\theta)}{\theta} \left(1 + \frac{\bar{\epsilon}}{\bar{\xi} - 1} + (1-\iota) \frac{\alpha}{1-\alpha} \bar{\xi} \right)^{-1} \tag{31}$$

The derivation is sketched in appendix A. Note that κ is declining in both θ (the degree of nominal rigidity) and $\bar{\epsilon}$ (the curvature of the demand parameter). Also $\kappa|_{\iota=0} < \kappa|_{\iota=1}$. That is, the New Keynesian Phillips curve is flatter with fixed firm-specific capital than with rental capital.

[13] With rental capital, the cost function is the value function from the cost minimisation problem. With fixed firm-specific capital, the cost function is simply $W_{t+k} N_{t+k}(j)$ where the production function is used to substitute for $N_{t+k}(j)$.

2.5 Economic policy

The specification of economic policy follows Galí et al. (2007). The central bank controls the risk-free interest rate, which it sets according to a simple Taylor rule

$$r_t = r + \phi_\pi \pi_t \tag{32}$$

The government budget constraint is

$$P_t T_t + R_t^{-1} B_{t+1} = B_t + P_t G_t \tag{33}$$

the linearisation of which becomes

$$b_{t+1} = \beta \left(b_t + g_t - t_t \right) \tag{34}$$

where $b_t = (B_t/P_{t-1} - B/P)\,Y$, $g_t = (G_t - G)/Y$ and $t_t = (T_t - T)/Y$. Fiscal policy is given by the rule

$$t_t = \phi_b b_t + \phi_g g_t \tag{35}$$

Government spending (normalised by steady-state output and expressed in deviations from steady state) evolves exogenously according to the following first-order autoregressive process

$$g_t = \rho_g g_{t-1} + \varepsilon_t \tag{36}$$

where $0 < \rho_g < 1$ and ε_t is white noise with variance σ_ε^2. With this specification, the government finances the exogenous disturbances to its spending in any given period partly through taxes, partly through the issuance of bonds.

2.6 Equilibrium

Market clearing requires that

$$Y_t = C_t + I_t + G_t \tag{37}$$

In log-linear form, this becomes

$$y_t = \frac{C}{Y} c_t + \frac{I}{Y} i_t + g_t \tag{38}$$

3 The consumption multiplier

As in Galí et al. (2007), we analyse the effects of government spending shocks emphasising the response of private consumption. Specifically, we focus on the peak response of aggregate private consumption following a shock to government spending normalised to one per cent of the level of output in the steady state. We refer to the peak in the impulse response as the consumption multiplier.

3.1 The model without real rigidities

To set the scene, figure 1 shows the consumption multiplier as a function of the fraction of rule-of-thumb consumers, λ, and as a function of the degree of price rigidity, θ, in the model analysed by Galí et al. (2007). This is equivalent to the model in section 2 when $h_o = h_r = \bar{\varepsilon} = 0$ and $\iota = 1$. That is, it is a version of the model with a rental market for capital, without habit formation in consumption, and with a constant elasticity of demand. The calibration of the remaining parameters follows the baseline calibration in Galí et al. (2007). Hence, we consider a time period to be one quarter, and we set $\delta = 0.025$, $\alpha = 0.33$, $\sigma = \eta = 1$, $\beta = 0.99$, $\lambda = 0.5$, $\gamma_g = 0.2$, $\phi_\pi = 1.5$, $\phi_b = 0.33$, $\phi_g = 0.1$, $\bar{\xi} = 6$, $\rho_g = 0.9$ and $\varphi = 0.2$. Finally, in the baseline calibration $\lambda = 0.5$ and $\theta = 0.75$. Note for future reference that this baseline calibration gives a value of the consumption multiplier of approximately 1.2.

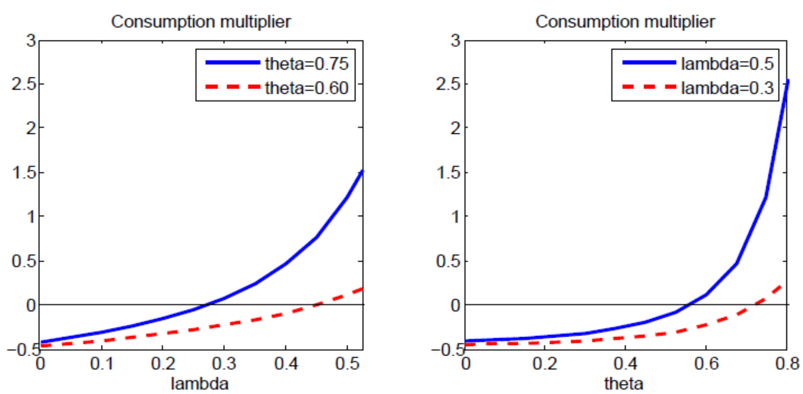

Figure 1: Impact consumption multiplier in the model by Galí et al. (2007) as function of λ, the fraction of rule-of-thumb consumers (left panel), and θ, the degree of price rigidity (right panel). Remaining parameters at baseline values.

Consider the solid lines first. These lines show the consumption multiplier in the Galí et al. (2007) model as a function of λ (left panel) and θ (right panel) with the other parameters remaining as under the baseline calibration. We see that, keeping θ fixed at 0.75, the consumption multiplier is positive only for values of λ larger than 0.3. Similarly, keeping λ fixed at 0.5, the multiplier is positive only for values of θ above a critical value between 0.5 and 0.6 corresponding to between two and three quarters of expected price stickiness. Hence, if we lower one of these two key parameters from the value chosen under the baseline calibration to one that is more realistic given the empirical evidence described in section 1, the consumption multiplier is no longer positive.

Considering the dashed lines, we see that by lowering one of the two parameters to a more plausible value – $\theta = 0.6$ and $\lambda = 0.3$ respectively – we make it harder to obtain a positive consumption multiplier for all values of the other parameter. For $\theta = 0.6$, the fraction of rule-of-thumb consumers needs to be close to 0.5 to drive the consumption multiplier above zero, and for $\lambda = 0.3$, the expected duration of prices must be longer than a year. Moreover, under our preferred calibration in which $\theta = 0.6$ and $\lambda = 0.3$ at the same time, the consumption multiplier is seen to be negative.

In sum, these pictures show that the positive response of consumption is a fragile result in two crucial dimensions. It relies on implausibly high values for the degree of nominal rigidity and the percentage of constrained agents. Our contribution is to provide a solution to this problem by reconciling a sizeable increase in consumption as in Gali et al. (2007) with reasonable values for the degree of nominal rigidity and the financial friction. We do this by adding real rigidities to the model.

3.2 Adding real rigidities

Motivated by the previous sensitivity analysis of the model in Galí et al. (2007), we now present responses from the model augmented with habit persistence, Kimball demand and fixed firm-specific capital. We set the fraction of rule-of-thumb consumers, λ, at 0.3 inspired by the empirical evidence discussed in section 1, and we set the degree of habit persistence of optimising households, h_o, equal to 0.85, a value which is within the range of values considered in the literature.[14] However, we let the degree of habit persistence of rule-of-thumb households be zero, that is, $h_r = 0$. This is to facilitate

[14] It falls between the value estimated by Christiano et al. (2005) and the one considered by Woodford (2003, ch. 5).

the interpretation that rule-of-thumb households are inherently different from optimising households by having an entirely static horizon.

The calibration of the curvature of the Kimball demand function, represented by $\bar{\varepsilon}$, is more difficult. As noted by Dossche et al. (2006), there is no agreement on what a plausible value might be for this parameter in the literature; estimates range from 1.3 (Bergin and Feenstra, 2000) to 471 (Kimball, 1995). In this section we therefore calibrate $\bar{\varepsilon}$ by fixing values for the slope of the New Keynesian Phillips curve, κ, and the degree of nominal rigidity, θ. This allows us to recover a value of $\bar{\varepsilon}$ implied by the expression for κ given in (31). We set θ at 0.6, cf. section 1, while we fix κ at 0.03 based on the reduced-form evidence on the slope of the New Keynesian Phillips curve in Galí et al. (2005) and Levin et al. (2007). The implied value of $\bar{\varepsilon}$ is 25.

It is possible that 25 is still too high a value for $\bar{\epsilon}$, at least according to the evidence provided by Dossche et al. (2006). They suggest that a value around 4 is more reasonable, though they find evidence of considerable variation across sectors. We note that we would need a higher value of $\bar{\epsilon}$ (around 40) if we had kept the rental capital assumption. This illustrates that different real rigidities may interact in the economy in a way that allows us to consider reasonable values for other parameters representing real and financial rigidities.[15] Similarly, if we are slightly less ambitious in bringing down the expected duration of prices, we may obtain a value of $\kappa = 0.03$ with $\bar{\epsilon} = 4$ in the version of our model with firm-specific capital. This requires us to accept an expected duration of prices of slightly more than 3 quarters instead of our benchmark $2\frac{1}{2}$, but still in the range of the plausible values according to Nakamura and Steinsson (2007).

Note that our calibration of κ implies a much flatter New Keynesian Phillips curve than in Galí et al. (2007), where $\kappa = 0.0858$. In the model without real rigidities, we would need a Calvo parameter of 0.85 to generate a slope of 0.03, clearly an unrealistic value given the empirical evidence available.

Figure 2 presents impulse responses to key macroeconomic variables under this calibration along with responses from the model by Galí et al. (2007).[16] The main result of our paper is that the responses of consumption are nearly identical in the two models. In both cases, we obtain a consumption multiplier

[15] The model's equilibrium dynamics for variables other than investment is not affected by the choice of assumption concerning the structure of the capital market. We therefore omit reporting the impulse responses for the rental capital case with Kimball demand and habit formation.

[16] The responses reported here are in percentage deviations from steady state and so they differ slightly from the ones reported in Galí et al. (2007), which are normalised by steady-state output.

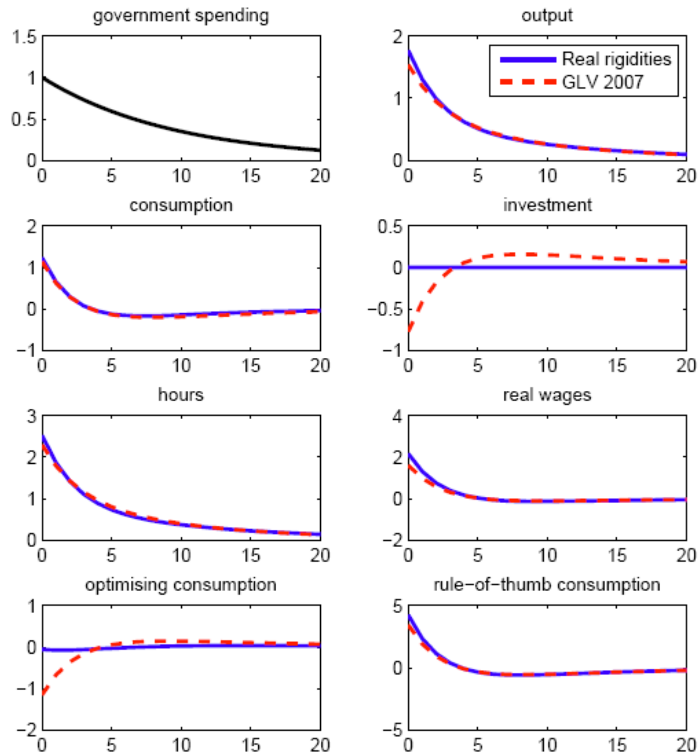

Figure 2: Impulse responses to a government spending shock normalised to one per cent of steady-state output for $\lambda = 0.5$ and $\theta = 0.75$ in the Galí et al. (2007) model (dashed lines), and for $\lambda = 0.3$ and $\theta = 0.6$ in an extended version of the model with real rigidities (solid lines).

of approximately 1.2. Hence, the introduction of real rigidities in the form of habit persistence in consumption, Kimball demand and fixed firm-specific capital allows us to generate the same consumption multiplier as in Galí et al. (2007) with an expected price duration of two and a half quarters (instead of four) and with only 30 per cent of financially constrained agents (instead of 50). The crucial difference between the two models is that, in the model with real rigidities, both the fraction of rule-of-thumb consumers and the degree of price rigidity are more in line with the empirical evidence.

Part of the explanation for our result is that, in the model with real rigidities, habit persistence works to mitigate the contractionary effect from Ricardian households by smoothing their response to the shock. Rule-of-thumb households still respond by increasing their consumption since the partial bond financing of the government spending shock makes current income go up. But with habit formation in consumption, optimising households need time to adjust to the lower level of consumption called for by the reduction in lifetime income that results from current *and* future taxation. This makes them reduce consumption less on impact of the shock. Though rule-of-thumb consumers now weigh less in the aggregate, the net effect on aggregate consumption is therefore unchanged.

This is not the only effect in play, however. With a relatively flat New Keynesian Phillips curve, a positive shock to government spending that increases firms' marginal costs by increasing aggregate demand in the economy has a smaller effect on inflation through the price-setting process. This makes the central bank respond by increasing interest rates less than in an economy with a steeper Phillips curve. This further moderates the negative consumption response of optimising consumers. It is the combination of habit formation in consumption and a less responsive demand effect through monetary policy that allows us to generate the same consumption multiplier as in Galí et al. (2007) for a lower percentage of rule-of-thumb consumers.

Importantly, the introduction of real rigidities that are known to increase the strategic complementarities in price setting, cf. Woodford (2003), allows us to reduce the slope of the Phillips curve without increasing the degree of nominal rigidity. In contrast, our analysis is consistent with fixing θ at 0.6 in keeping with microeconomic evidence on the frequency of price changes. Note also from figure 2 that the responses of the other aggregate variables are also nearly identical in the models. The only exception, of course, is investment, which is constant by assumption in the model with firm-specific capital.[17]

3.3 Sensitivity analysis

The relative importance of habit formation and real rigidities affecting inflation dynamics for the consumption response can be seen from figure 3, in which we report the consumption multiplier as a function of h_o keeping $\kappa = 0.03$ (left panel), and κ keeping $h_o = 0.85$ (middle panel) when $\lambda = 0.3$ (in contrast to the baseline $\lambda = 0.5$). Remaining parameters are at their baseline values. On the left panel it is seen that reducing the degree of habit persistence lowers

[17]As argued by Furlanetto (2007), the model in Galí et al. (2007) exhibits a counterfactually large response of the real wage. However, once he introduces a nominal wage rigidity that smooths the wage response, the increase in consumption is confirmed. We have also considered a version of the model with real rigidities augmented with nominal wage rigidities. Results are qualitatively similar to the ones reported here. For the sake of completeness, they are reported in appendix B.

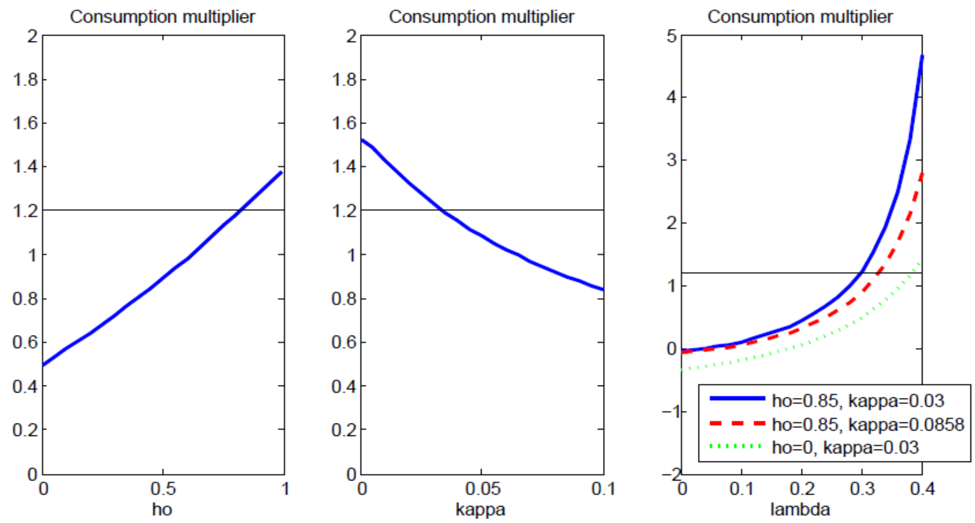

Figure 3: Impact consumption multiplier as a function of h_o, the degree of habit persistence of optimising households (left panel), and κ, the slope of the New Keynesian Phillips curve (middle panel), for $\lambda = 0.3$ and $\theta = 0.6$. The right panel shows the multiplier as a function of λ for $h_o = 0.85$, $\kappa = 0.03$ and $\theta = 0.6$.

the impact response of private consumption following a shock to government spending. In the extreme case without habit persistence ($h_o = 0$), the impact of Kimball demand curves and firm-specific capital can be seen in isolation. The consumption multiplier is still positive around 0.5 in this case.

The middle panel in figure 3 shows the consumption multiplier as a function of κ, the slope of the New Keynesian Phillips curve. As noted in section 2, this slope is inversely related to $\bar{\epsilon}$, meaning that κ goes from 0 to 0.1 as $\bar{\epsilon}$ goes from infinity to 0.1. That is, $\bar{\epsilon}$ declines as we move from left to right on the graph. When $\lambda = 0.3$ in the model with habit formation, we see that κ has to be close to 0.03 to generate a consumption multiplier close to 1.2. In particular, increasing the slope of the New Keynesian Phillips curve reduces the multiplier. For $\kappa = 0.0858$ as in the baseline calibration of Galí et al. (2007), we see that the multiplier falls to approximately 0.8 even when habit persistence curbs the contractionary effect from the 70 per cent of households that optimise intertemporally.

The right panel in figure 3 shows the consumption multiplier as a function of λ, the fraction of rule-of-thumb consumers, for three different assumptions about real rigidities. The range is restricted to values of λ for which the equilibrium is determinate in all three cases. The solid line shows the case we prefer with all rigidities included, that is, $h_0 = 0.85$ and $\kappa = 0.03$. Notice that some households need to consume according to a rule of thumb for the consumption multiplier to become positive (values of λ above 0.05). For $\lambda = 0.15$, the value suggested by the posterior distribution estimated by López-Salido and Rabanal (2008), the consumption multiplier is positive but small. However, the consumption multiplier is quite sensitive to changes in λ above this value. When 20 per cent of households are rule-of-thumb consumers, for instance, the multiplier is approx. 0.5, before reaching the 1.2 obtained in the Galí et al. (2007) model for $\lambda = 0.3$. The dashed line shows the multiplier's sensitivity in the case with habit formation ($h_0 = 0.85$) but with a slope of the Phillips curve given as in the baseline calibration of Galí et al. (2007). Similarly, the dotted line shows the case with $\kappa = 0.03$, as in our calibration of the model with fixed firm-specific capital and Kimball demand, but without habit formation ($h_0 = 0$). The case without habit formation is the one requiring the highest fraction of rule-of-thumb consumers to get the multiplier of 1.2 that we target, while the case with habit formation but a relatively steep Phillips curve is closer to (though strictly below) the line representing our preferred case. This suggests that habit formation is the more important of the real rigidities in driving our result.

3.4 Discussion

Other authors have provided explanations of a positive consumption response to a government spending shock without resorting to deviations from Ricardian equivalence. Examples are the introduction of a complementarity between hours and consumption (López-Salido and Rabanal, 2008, following Linnemann, 2006)[18], a complementarity between private consumption and public spending (Bouakez and Rebei, 2007), productive government spending (Linnemann and Shabert, 2005), and deep habit formation (Ravn et al., 2006). We note that our approach is very different from theirs. We investigate the impact of standard real rigidities that have proven useful in other areas of the literature, especially to explain the effects of monetary shocks (e.g. Smets and Wouters, 2007, and Altig et al., 2005), and we show that they are also useful for explaining fiscal shocks. In particular, in resorting to deviations from Ricardian equivalence when explaining the response of private consumption, these real rigidities reduce the fraction of non-Ricardian households needed. As non-Ricardian households represent a deviation from the standard optimis-

[18] See Bilbiie (2008) for a critical warning on this approach.

ing framework of DSGE models, this may increase the appeal of non-Ricardian behaviour as an explanation of the economy's response to fiscal policy shocks.

We also note that López-Salido and Rabanal (2008) have achieved the same goal with their assumption of complementarity between private consumption and hours. Indeed, both features appear to be important to explain features of the data in an estimated version of the model, where the estimated fraction of rule-of-thumb consumers is 0.15. However, the complementarity affects the Euler equation in a very similar way compared to introducing non-Ricardian agents. Therefore, it is not surprising that the role of non-Ricardian agents is diminished when the two approaches are integrated in the same model.

With the possible exception of deep habits, the various explanations of a positive response of private consumption to a government spending shock share the flaw that consumption increases on impact before declining monotonically. In contrast, the empirical papers cited in section 1 all find a persistent hump-shaped response. Galí et al. (2007) conjecture that habit persistence can work to this effect in a model with rule-of-thumb consumers, but our results show otherwise. Habit persistence influences optimising consumers' behaviour (their consumption response is in fact hump-shaped albeit negative), but not the behaviour of rule-of-thumb consumers, because these agents have a static horizon. Therefore, the monotonic response by rule-of-thumb agents is inherited by aggregate consumption. To obtain a hump-shaped response in aggregate consumption, a large hump-shaped response of rule-of-thumb consumption would be needed. This can be achieved only if labour income reacts in a hump-shaped way. However, a large monotonic response of hours worked, even in the model with sticky wages, rules out this possibility. Hence, while non-Ricardian behaviour may be central to understanding household responses to fiscal shocks, the rule-of-thumb formalisation may be too crude to adequately account for the dynamics of these responses.

4 Concluding remarks

This paper shows that the rule-of-thumb theory of consumption does not rely on a high degree of nominal rigidity or a large financial friction when accounting for a positive response of private consumption to a positive government spending shock. When empirically plausible real rigidities are added to the model, they interact with nominal and financial rigidities in ways that allow us to specify more reasonable parameter values for all the rigidities at work in the model. Hence, we believe that this paper complements the analysis in Galí et al. (2007) by showing how the rule-of-thumb theory of consumption becomes more appealing once realistic features are added to the model. However, the results suggest that rule-of-thumb behaviour is too crude a mechanism for adequately accounting for the timing of household responses.

Interestingly, the same combination of real rigidities that we apply has been used in the previous literature to replicate conditional responses to other shocks, especially monetary shocks and technology shocks. Habit persistence has been used to reproduce the hump-shaped response of output and consumption on the impact of a monetary shock, while Kimball demand curves and firm-specific capital have been used to reconcile the microeconomic evidence on the degree of price rigidity with the macroeconomic evidence on the slope of the New Keynesian Phillips curve, cf. references in section 1. In a companion paper, Furlanetto and Seneca (2007) show that the interaction of nominal, real and financial rigidities is also very helpful in accounting for the responses of hours worked following a productivity shock.

Thus, at a more general level, this paper contributes to this literature by showing how nominal and real rigidities may interact with financial frictions in ways that generate plausible responses following empirically important disturbances to the economy. We believe this is a further indication that, while the simple basic real business cycle framework is an important benchmark both conceptually and methodologically, a realistic model of the economy is likely to be one in which many frictions and rigidities interact. Providing further evidence on how this may occur – and not least further empirical evidence on the relative importance of these rigidities and frictions along the lines of Coenen and Straub (2005), Forni et al. (2007) and López-Salido and Rabanal (2008) – is, we believe, an important topic for further research in macroeconomics.

A Appendix

The first-order condition to the price-setting problem is:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k}(j) \left[P_t^* \left(1 - \xi\left(X_{t+k}(j)\right)\right) - \xi\left(X_{t+k}(j)\right) P_{t+k} MC_{t+k}(j) \right] \right\} = 0$$

We log-linearise this first-order condition to get

$$0 = E_t \sum_{k=0}^{\infty} (\theta\beta)^k \left[\left(1 - \bar{\xi}\right) p_t^* - \left(1 - \bar{\xi}\right) mc_{t+k}(j) - \left(1 - \bar{\xi}\right) p_{t+k} - \bar{\epsilon}\left(p_t^* - p_{t+k}\right) \right]$$

where we have substituted in log-linearisations of (21) and (18). Since

$$mc_{t+k}(j) = mc_{t+k} - (1-\iota)\frac{\alpha}{1-\alpha}\bar{\xi}\left(p_t^* - p_{t+k}\right)$$

where mc_{t+k} is the average marginal cost in log-linear terms, we get

$$\begin{aligned}
&\frac{1}{1-\theta\beta}\left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}+(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\right)\left(p_t^* - p_{t-1}\right)\\
&= E_t\sum_{k=0}^{\infty}(\theta\beta)^k\left[\left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}\right)\left(p_{t+k}-p_{t-1}\right)+mc_{t+k}-(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\left(p_{t-1}-p_{t+k}\right)\right]\\
&= \left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}+(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\right)\pi_t + mc_t\\
&+ \frac{1}{1-\theta\beta}\left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}+(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\right)E_t\left(p_{t+1}^* - p_t\right)\\
&+ \frac{\theta\beta}{1-\theta\beta}\left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}+(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\right)\pi_t
\end{aligned}$$

As shown by Eichenbaum and Fisher (2007), the price index implies that

$$p_t^* - p_{t-1} = \frac{\pi_t}{1-\theta}$$

Using this gives

$$\begin{aligned}
\frac{\pi_t}{1-\theta} &= (1-\theta\beta)\pi_t + (1-\theta\beta)\left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}+(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\right)^{-1} mc_t\\
&+ \frac{\theta\beta}{1-\theta}E_t\pi_{t+1} + \theta\beta\pi_t
\end{aligned}$$

Rearranging gives the New Keynesian Phillips curve in the text:

$$\pi_t = \frac{(1-\theta\beta)(1-\theta)}{\theta}\left(1+\frac{\bar{\epsilon}}{\bar{\xi}-1}+(1-\iota)\frac{\alpha\bar{\xi}}{1-\alpha}\right)^{-1} mc_t + \beta E_t\pi_{t+1}$$

B Appendix

An unpleasant feature of the model presented in the previous section is that, independently of the presence of real rigidities, it implies a large increase in the real wage which is counterfactual. Many empirical studies – Blanchard and Perotti (2002), Perotti (2005), Fatas and Mihov (2002) among many others

– find a zero response or at most a tiny positive response, in general not statistically significant. Furlanetto (2007) shows that by introducing sticky wages in the model, it is possible to reconcile a plausible conditional response of real wages and a positive and sizeable response of private consumption on the impact of a government spending shock. In other words, the Galí et al. (2007) result does not rely on the large counterfactual response of real wages, as one might intuitively think, but is confirmed in a more general setting with wage rigidities. For the sake of completeness, we want to show that real rigidities can substitute for nominal and financial rigidities, also in a framework with sticky wages. As shown in Furlanetto and Seneca (2007), with sticky wages and habit formation in consumption, equation (15) is substituted by the following equation for wages

$$\pi_t^w = \beta E_t\left(\pi_{t+1}^w\right) + \kappa_w\left(mrs_t - (w_t - p_t)\right) \tag{39}$$

where $\pi_t^w = w_t - w_{t-1}$ is wage inflation, mrs_t is the average marginal rate of substitution given by

$$mrs_t = \chi_r\left(c_t^r - h_r c_{t-1}^r\right) + \chi_o\left(c_t^o - h_o c_{t-1}^o\right) + \varphi n_t \tag{40}$$

and the slope coefficient κ_w is

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

Here, ϕ_w governs the size of wage adjustment costs à la Rotemberg (1982).[19] We calibrate ε_w equal to 4 and ϕ_w equal to 454.5. This choice yields the same New Keynesian Phillips curve for wages as in a Calvo setting à la Erceg et al. (2000) with four quarters of wage stickiness.

A second criticism that can be raised to the Galí et al. (2007) model concerns the calibration of the inverse of the labour supply elasticity φ. Galí et al. (2007) are forced to set it at 0.2 to make the model determinate. However, the determinacy region is larger under sticky wages and therefore we can raise φ to more plausible values. We set φ equal to 3, consistent with a labour supply elasticity of 1/3, consistent with considerable microeconomic

[19] 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, 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 θ_w is the Calvo parameter for wage setting.

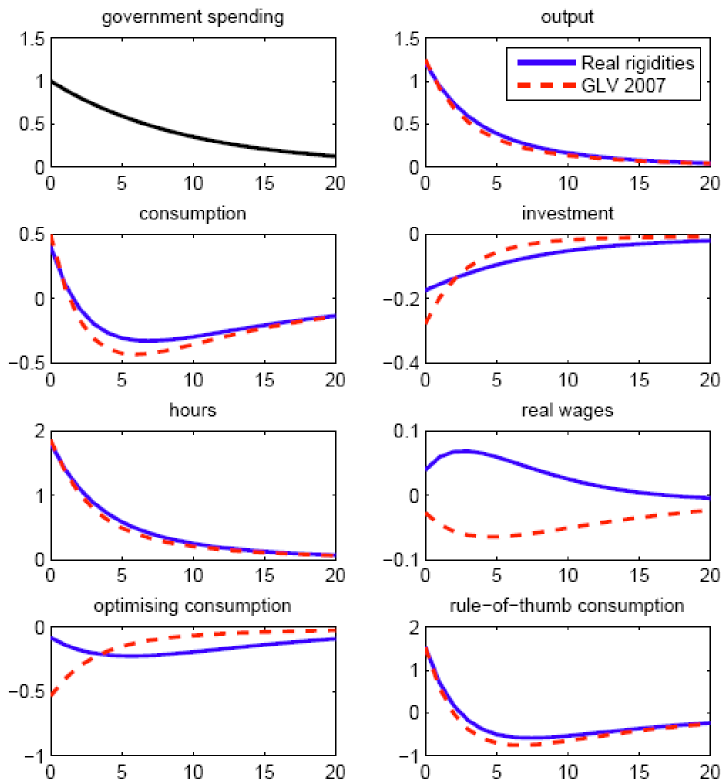

Figure 4: Impulse responses to a government spending shock normalised to one per cent of steady-state output for $\lambda = 0.5$ and $\theta = 0.75$ as in the Galí et al. (2007) model augmented with sticky wages (dashed lines), and for $\lambda = 0.3$ and $\theta = 0.6$ in an extended version with real rigidities in addition to sticky wages (solid lines).

evidence. In figure 4 we plot the impulse responses for the model in Galí et al. (2007) augmented with sticky wages along with a model further extended with real rigidities as in section 2 (Kimball demand and habit consumption, while keeping the rental capital assumption).

We see that the model with real rigidities can reproduce approximately the same multiplier as the model without real rigidities under only 30 per cent of constrained agents. Thus, once again, real rigidities can substitute for nominal rigidities and financial frictions. Note also that real wages respond very little in both cases due to wage adjustment costs.

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