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Rule-of-Thumb Consumers and Labor Tax Cut Policy at the Zero Lower Bound

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Rule-of-Thumb Consumers and Labor Tax Cut Policy at the Zero Lower Bound

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Abstract

This paper shows that a labour tax cut can increase output in a model where the zero lower bound on the nominal interest rate binds due to a negative demand shock. The model is a basic new-Keynesian one with non-Ricardian (also known as rule-of-thumb) households (along with the usual Ricardian ones) who spend the increase in their disposable income after the tax cut. Besides price rigidity our result requires wage rigidity which attenuates the effect of the negative demand shock on the real wage. This finding stands in contrast to those of Eggertsson (2011) and Christiano, Eichenbaum and Rebelo (2011) who argued in favour of a labor tax increase. We assume a balanced-budget labour tax cut which is financed through income taxes levied in a progressive way unlike previous papers operating with lump-sum taxes.

JEL classification: E52, E62

Keywords: fiscal policy, zero lower bound, labor tax cut, New Keynesian, balanced budget, progressive taxation

1 Introduction

Following the enaction of the American Recovery and Reinvestment package of 2009 in the United States there has been discussion on the sign and magnitude of fiscal multipliers. The \$787 billion fiscal package contains payroll tax cuts as well[1]. On one hand some influential papers concluded that an increase in non-productive government spending can be very effective in stimulating the economy under the recent zero nominal interest rate environment (see, e.g., Christiano et al. (2011), Eggertsson (2010) and Woodford (2010)). On the other hand it turned out that labor tax cuts can be contractionary when the zero lower bound on the nominal interest rate is binding (see Eggertsson (2010a, 2010b)).

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[1]In December 2011 President Obama announced that the payroll tax cut is extended until end of 2012.

This paper contributes to the literature by showing that the incorporation of rule-of-thumb (or non-Ricardian)[2] consumers into the baseline new-Keynesian model can render labor tax cut[3] policy expansionary when nominal interest rate is zero. Our finding requires the presence of price and wage-setting frictions which are, by now, standard features of micro-founded general equilibrium models (see, e.g., Woodford (2003))[4].

Our paper builds on previous literature (see Christiano et al. (2011), Eggertsson (2011) and Woodford (2011)) in the sense that the zero lower bound on the nominal interest rate becomes binding due to a discount factor shock (i.e. a negative demand shock). However, we depart from previous papers which assume that the government budget is balanced using lump-sum taxes[5]. In particular, the government budget of our model is balanced each period through labor tax revenue which is collected in a progressive manner. Progressive taxation which acts as an automatic stabiliser is a well-known feature of modern states (see Mattesini and Rossi, 2012) and is introduced into our model following Guo and Lansing (1998).

As Bils and Klenow (2008) and Christiano (2010) argued it matters whether we cut the employer's or the employee's part of the labor taxes. In the latter case an average labor tax cut acts like a traditional stimulus tax cut working through the labor supply, and, thus, wage-setting frictions under which labor supply curve is potentially irrelevant make a difference. However, in the previous case the payroll tax cut directly affects the marginal cost and, as we argue below, acts like a further deflationary factor on the economy besides the negative demand shock. In this paper it is the employee's part of the average labor tax which is reduced.

First, let us discuss what the baseline log-linear new-Keynesian model with only price rigidity and perfectly competitive labour market with flexible wages delivers in the absence of non-Ricardian consumers in response to a labour tax cut. Christiano et al. (2011) shows that a discount factor shock, which can be interpreted as a negative demand shock, leads to deflation and a fall in output, consumption and the marginal cost. In a similar model Eggertsson (2011) shows that cutting the labor tax rate has effects similar to the discount factor shock i.e. a random fraction of firms that can change their product price will lower the price because they face a reduction in their production costs. While other firms who

[2]Rule-of-thumb households are excluded from the financial market. Hence, they have no consumption-savings tradeoff (lack of Euler equation) and their decision problem is restricted to the optimal choice between consumption and leisure. The inclusion of rule-of-thumb households into DSGE models is a trivial way of generating incomplete asset markets.

[3]In a recent paper Bilbiie et al. (2012) has shown that cuts in lump-sum taxes stimulate output and raises welfare in an economy featuring two types of households (savers and borrowers), price rigidity and which is constrained by the zero lower bound on the nominal interest rate.

[4]The most relevant literature on models containing rule-of-thumb consumers are Bilbiie (2008) and Gali et al. (2007). The model used in this paper is closest to Ascari et al. (2011), Furlanetto (2011), Furlanetto and Seneca (2009) who enrich the model of Gali et al. (2007) with wage-setting frictions.

[5]There are two exceptions. One of them is Coenen et al. (2012) who simulate various middle-sized DSGE models including rule-of-thumb households. We differ from that paper for at least three reasons. First, the zero lower bound period in our paper is generated endogenously as a result of a negative demand shock instead of arbitrarily fixing the interest rate for a given time period. Second, we employ simpler models than theirs so that we can provide intuition on what model features we need in order for the labour tax cut policy to be expansionary. Third, we explore the case of balanced budgets with progressive taxation as well.

The second exception is Drautzberg and Uhlig (2011) who study a model similar to Smets and Wouters (2007) with non-Ricardian agents and distortionary taxation. However, they do not cover labour tax cuts.

cannot reset their price due to price stickiness will produce less and also decrease their demand for labor. When nominal interest rate is zero, the deflationary effect of the labor tax cut is coupled with a rise in the real interest rate that depresses consumption. Also, Ricardian consumers associate the current tax cut with future rises in taxes and decrease their consumption to save up (Ricardian equivalence is valid). Thus, with only Ricardian consumers in the model the tax cut cannot be stimulative.

However, the labor tax cut happens to be expansionary if we incorporate non-Ricardian consumers and wage rigidity into the model. Following the tax-cut Non-Ricardian households consume the rise in their disposable income generating a demand effect. Due to the higher consumption demand of non-Ricardian households firms which cannot alter their price as a result of price rigidity will demand more labor to be able to produce more. In the absence of an imperfectly competitive labour market with nominal wage inertia[6] the discount factor shock and the labor tax cut would lead to an enourmous decline in the marginal cost (which equals to the real wage due to the constant returns-to-scale production function[7]). But the introduction of wage rigidity into the model attenuates the reaction of real wage to the discount factor shock so that the real disposable income of non-Ricardians can rise following the tax cut. Hence, in our setting the effects of the negative demand shock is less severe if there is a simultaneous fall in the labor tax during the zero lower bound period. Our finding is completely in contrast to Christiano et al. (2011) who argue for a labor tax rise in the zero lower bound situation using a middle-sized DSGE model without rule-of-thumb agents.

Our findings are based on deterministic labor tax cut experiments conducted using the codes of Christiano et al. (2011) who studied small and middle-sized new-Keynesian models in log-linear form without non-Ricardian consumers. Thus, in our experiments the discount factor shock and the fiscal action (the labor tax cut) are on for a deterministic period of time. This modelling strategy received considerable attention in the recent literature. Here we touch upon two issues. First, Carlstrom et al. (2012) assert that inflation and output impulse responses of a negative demand shock might exhibit unorthodox behaviour—they rise instead of falling—depending on the number of periods for which the interest rate is fixed when there are state variables like capital in the log-linear model. However, we do not encounter such a problem for our calibrated value of the length of the shock[8]. Second, a number of papers[9] raise concerns about the accuracy of the first-order perturbation in modelling the zero-lower bound. However, Christiano and Eichenbaum (2012) present evidence that first-order perturbation remains to be a fairly good approximation to the non-linear model.

There is a growing empirical literature which founds labor tax cuts being stimulative. In a well-known study using narrative accounts Romer and Romer (2010) found that tax

[6]To motivate imperfectly competitive labor markets households (independently of whether they are Ricardian or non-Ricardian origin) become members of unions which set wages for them. It is costly for the unions to change wages because of wage adjustment costs. Hence, we have nominal wage rigidity. See details in the main text.

[7]This explanation is based on a model without physical capital.

[8]Depending on the size and length of the discount factor and the fiscal shock (tax cut) the model endogenously generates the date at which the zero lower bound starts and ceases to bind.

[9]See, e.g., Braun and Körber (2011) and Mertens and Ravn (2011). Especially, Braun and Körber (2011) argue using a non-linear model that the ignorance of price adjustment cost in the aggregate feasibility constraint distorts the size and even sign of fiscal multipliers obtained from the log-linear model in which the price adjustment cost is zero.

increases are contractionary. Also, Mertens and Ravn (2011) found using a new narrative account of federal tax liability changes to proxy tax shocks that the short run effects of a tax decrease on output are positive and large. Hall (2009) reviews several empirical studies arguing that households do respond with an increase in their consumption expenditures to a temporary cut in labour tax. Thus, there is enough empirical evidence in support of the positive effects of a labor tax cut.

The rest of the paper is organised as follows. Section 1 describes the agents in the model and their assumed behaviour. Section 2 contains the calibration. In Section 3 we conduct experiments in various models with and without capital to investigate into the effects of the labor tax cut. The last section concludes.

1.1 Households

1.1.1 Ricardians

There are two types of households: Ricardians and non-Ricardians. Ricardian households are able to smooth their consumption using state-contingent assets (risk-free bonds) while non-Ricardians cannot. The share of Ricardian and non-Ricardian households in the economy is λ and $1-\lambda$, respectively. The instantenous utility function of type $i \in \{o, r\}$ household which can be Ricardian (optimiser (OPT), o) or non-Ricardian (or rule-of-thumb (ROT), r), is given by:

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

where C_t^i ($\bar{C}_t^i$) denotes the time-t consumption (aggregate consumption) of type $i \in \{o, r\}$ household and parameter h_i governs the degree of habit formation in consumption. This specification follows Furlanetto and Seneca (forthcoming) who argue that habit formation is external in the sense that household chooses its own current consumption irrespecitve of its past consumption while it is internal to the extent that household of type i relates its current consumption to aggregate consumption of the same class of households. When $h_i = 0$ there is no habit formation. N_t^i is hours worked by household of type i.

First, we discuss the problem of Ricardian households. They maximise their lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta_t U_t^i, \tag{2}$$

where E_0 is the expectation operator representing expectations conditional on period-0 information and β is the discount factor. This maximisation of the optimiser household is subject to a sequence of budget constraints[10]:

$$\begin{aligned} P_t C_t^o + R_t^{-1} E_t\{B_{t+1}^o\} &= (1-\tau_t^{l,o}) W_t N_t^o + (1-\tau_t^{k,o}) P_t R_t^k \mathcal{U}_t K_t^o - \Omega(\mathcal{U}_t) K_t^o \\ &\quad + B_t^o + D_t^o - P_t T_t^o - P_t I_t^o - F_t - P_t S^o \end{aligned} \tag{3}$$

where P_t is the aggregate price level, W_t is the nominal wage and N_t^o is hours worked by OPT. Thus, $W_t N_t^o$ is the labor income received by the optimiser household. R_t^k is the real

[10] For the rest of the paper, a variable without a time subscript denotes steady-state value.

rental rate on capital, K_t^o, in real terms and I_t is real investment, T_t^o are lump-sum taxes (or transfers, if negative) paid by the household and $\tau_t^{l,o}$ ($\tau_t^{k,o}$) is an average tax rate on the labor, l (capital, k) income of optimisers (hence, the superscript o). Thus, $(1-\tau_t^{k,o})R_t^k K_t^o$ is the after-tax income earned on capital. D_t^o are the dividends from ownership of firms. Further, B_{t+1}^o is the amount of risk-free bonds and R_t is the nominal interest rate. Following Gali et al. (2007) and Rossi (2012) we assume, without loss of generality, that the steady-state lump sum taxes (S^o) are chosen in a way that steady-state consumption of ROT and OPT households equal in steady-state. Hence, S^o is a steady-state lump-sum tax used to facilitate the equality of the steady-state consumptions of ROT and OPT households. F_t stands for a nominal union membership fee (see later on it below). For an alternative approach when steady-state consumptions are not equal see Natvik (2008). Here $\Omega(\mathcal{U}_t)$ is the storage cost of the part of capital that is not utilised for production at time t. Following Christiano et al. (2005) we assume that the functional form for the storage cost of capital is $\Omega(\mathcal{U}_t) = \ell_1(\mathcal{U}_t - 1) + (\ell_2/2)(\mathcal{U}_t - 1)^2$ with $\ell_1 > 0$ and $\ell_2 > 0$. In steady-state we set $\mathcal{U}_t = \mathcal{U} = 1$ and $\Omega(1) = 0$, $\Omega'(1) > 0$ and $\Omega''(1) > 0$.

Also the optimiser household takes into consideration the evolution of capital stock

$$K_{t+1}^o = (1-\delta)K_t^o + \left[1 - S\left(\frac{I_t^o}{I_{t-1}^o}\right)\right] I_t^o, \tag{4}$$

when choosing the level of capital optimally. In the latter equation δ stands for the depreciation rate of capital. As standard in the literature (see e.g. Smets and Wouters (2007)) investment is subject to adjustment costs of the form, $S\left(\frac{I_t^o}{I_{t-1}^o}\right)$. In general, S is chosen such that $S'(1) = 0$, $S''(1) = \phi_{Inv}$. Using investment-adjustment costs we depart from Gali et al. (2007) who, instead, used capital adjustment costs.

In summary, the optimiser household maximises its lifetime utility with respect to its budget constraint, the evolution of capital and function characterising the storage cost of capital.

The OPT household first-order conditions (FOCs) with respect to consumption (C_t^o), investment (Inv_t^o), capital (K_{t+1}^o), bonds (B_{t+1}^o) and utilisation rate ($\mathcal{U}_t$) are:

$$\frac{\partial U_t^i}{\partial C_t^i} = (C_t^i - h_i \bar{C}_{t-1}^i)^{-\sigma} = \lambda_t, \text{ with } i = o, \tag{5}$$

$$\beta_{t+1} E_t \mu_{t+1} S'\left(\frac{Inv_{t+1}^o}{Inv_t^o}\right)\left(\frac{Inv_{t+1}^o}{Inv_t^o}\right)^2 = \lambda_t - \mu_t\left(1 - S\left(\frac{Inv_t^o}{Inv_{t-1}^o}\right)\right) + \mu_t S'\left(\frac{Inv_t^o}{Inv_{t-1}^o}\right)\frac{Inv_t^o}{Inv_{t-1}^o}, \tag{6}$$

$$\beta_{t+1} E_t\left(\lambda_{t+1}(1-\tau_{m,t+1}^{k,o})R_{t+1}^K \mathcal{U}_{t+1} - \Omega(\mathcal{U}_{t+1}) + \mu_{t+1}(1-\delta)\right) = \mu_t, \tag{7}$$

$$\beta_{t+1} E_t\left(\lambda_{t+1}\frac{1+R_{t+1}}{1+\pi_{t+1}}\right) = \lambda_t, \tag{8}$$

$$(1-\tau_{m,t}^k)R_t^k = \Omega'(\mathcal{U}_t), \tag{9}$$

where λ_t and μ_t are the multipliers associated with the budget constraint (equation (3)) and with the evolution of capital (equation (4)) in the Lagrangean representation of the OPT household's problem. Also let us define Tobin's Q as $Q_t \equiv \mu_t/\lambda_t$. The equations above can be described as follows. Equations (5), (6), (7) and (8) define, respectively, the marginal utility of consumption, the evolution of Tobin's Q, the capital Euler equation and the bond Euler equation. In all the above equations that contain expectations we ignore covariance terms. $\tau^k_{m,t}$ is the marginal tax rate on capital.

The linearised[11] version of equation (8) is the intertemporal Euler equation:

$$c^o_t = \frac{h_o}{1+h_o} c^o_{t-1} + \frac{1}{1+h_o} E_t c^o_{t+1} - \frac{1-h_o}{1+h_o}\frac{\beta}{\sigma}[dR_t - E_t\pi_{t+1} - dr_t], \tag{10}$$

where $c^o_t \equiv \log(C^o_t/C)$, $\pi_t \equiv \log(P_t/P_{t-1})$ is the time-t rate of inflation, $dR_t \equiv R_t - R$ ($dr_t \equiv R^{\text{real}}_t - R^{\text{real}}$), i.e. the deviation of nominal (real) interest rate from its steady-state value. dr_t can also be interpreted as the discount factor shock[12]. Notice that $h_o = 0$ delivers the usual Euler equation without habit formation.

The combination of equation (7) and the definition of Tobin's Q results, after linearisation, in the following expression[13]:

$$q_t = \beta E_t q_{t+1} - \beta[(1-\tau^k)R^k + (1-\delta)](dR_t - dr_t + E_t r^k_{t+1}) - R^k \hat{\tau}^k_{m,t}, \tag{11}$$

where $q_t \equiv \log(Q_t/Q)$, $k_t \equiv \log(K_t/K)$ and $r^k_t \equiv \log(R^k_t/R^k)$. It is instructive to observe that the discount factor shock (dr_t) appears in the capital-Euler equation (11) as well causing a decline in Tobin's q when $dr_t < 0$.

Similarly, the substitution of the definition of Tobin's Q into equation (6) leads to a dynamic relationship between investment and the implicit price of capital (i.e. Tobin's Q) which can be linearised to yield:

$$inv_t = \frac{1}{1+\beta} inv_{t-1} + \frac{\beta}{1+\beta} E_t inv_{t+1} + \frac{1}{\phi_{Inv}(1+\beta)} q_t, \tag{12}$$

where $inv_t \equiv \log(Inv_t/Inv)$.

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[11] The fact that Eggertsson (2010) log-linearise while Christiano (2010) linearise the same model does not affect the main conclusions. Here we follow the latter strategy.

[12] Following the appendix of Christiano (2010) the time varying discount factor is made equal to the inverse of the real interest rate (R^{real}_t) :

$$\beta_t = \frac{1}{1+R^{\text{real}}_t}$$

which can be linearised as:

$$\beta\hat{\beta}_t = -\frac{1}{(1+r)^2} dr_t,$$

where $\hat{\beta}_t \equiv (\beta_t - \beta)/\beta$ and $dr_t \equiv R^{\text{real}}_t - R^{\text{real}}$. It follows by using the steady-state condition $\beta = 1/(1 + R^{\text{real}}) = 1/(1+R)$ that:

$$\hat{\beta}_t = \beta dr_t.$$

[13] Here we depart from Gali et al. (2007) by assuming investment adjustment costs instead of their capital adjustment costs. Investment adjustment costs are more plausible empirically and widely used in middle-sized DSGE models like the Smets-Wouters (2007) model.

Also the linear version of the evolution of capital in equation (4) can be written as:

$$k_{t+1} = \delta inv_t - (1-\delta)k_t. \tag{13}$$

The linearised version of equation (9) is:

$$r_t^k - \frac{1}{1-\tau_m^k}\hat{\tau}_{m,t}^k = \Omega_u u_t.$$

where $\Omega_u \equiv \ell_1/\ell_2$ with $\ell_1 \equiv \partial\Omega_t/\partial\mathcal{U}_t$ and $\ell_2 \equiv \partial^2\Omega_t/\partial^2\mathcal{U}_t$.

The labor supply of OPT household is determined by the union's problem (discussed below).

1.1.2 Non-Ricardians

Non-Ricardian households cannot invest either into physical capital or into bonds. In other words, they are excluded from financial and capital markets. Hence, this is the case of limited asset market participation. Therefore, ROT do not make consumption-savings decision (i.e. the lack of consumption Euler equation). ROT households' consumption depends on their disposable income—i.e. the labor income after taxation, $(1-\tau_t^{l,r})W_t N_t^r$—which is reflected by their budget constraint:

$$\int_0^1 P_t(i)C_t^r(i)di = (1-\tau_t^{l,r})W_t N_t^r - P_t S^r, \tag{14}$$

where $C_t^r(i)$ and N_t^r are, respectively, the consumption of product i and hours worked by rule-of-thumb households. The steady-state lump-sum tax, S^r, ensures that the steady-state consumption of each types of households coincide.

ROT agents exploit relative price differences in the construction of their consumption basket and, in optimum, they obtain:

$$P_t C_t^r = \int_0^1 P_t(i)C_t^r(i)di.$$

Thus, a ROT household maximises its utility (equation (2) with $i = r$) with respect to its budget constraint (equation (14)).

The budget constraint of ROT households in equation (14) can be expressed in linear form as:

$$c_t^r = w_t + n_t^r - \chi\hat{\tau}_t^{l,r},$$

where $\hat{\tau}_t^{l,r} \equiv \tau_t^{l,r} - \tau^{l,r}$, $\chi \equiv 1/(1-\tau^{l,r})$.

ROT households delegate their labor supply decision to unions.

1.2 Firms

The intermediary goods are produced by monopolistically competitive firms of which a randomly selected $1-\xi^p$ fraction is able to set an optimal price each period as in Calvo (1983) while the remaining ξ^p fraction keep their price fixed. Intermediary good j, denoted as $Y(j)$, is produced by a constant returns-to-scale Cobb Douglas technology:

$$Y_t(j) = [\mathcal{U}_t K_{t-1}(j)]^{\alpha} [N_t(j)]^{1-\alpha}, \tag{15}$$

where $K_t(j)$ is capital owned by firm j, $\mathcal{U}_t$ is the degree of capital utilisation and hours worked, $N_t(j)$, is an aggregator of different labor varieties:

$$N_t(j) = \left(\int_0^1 [N_t(j,z)]^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dz \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}},$$

where $N_t(j,z)$ stands for quantity of variety z labor employed by firm j.

There is a competitive firm which bundles intermediate goods into a single final good through the Kimball (1995) aggregator:

$$\int_0^1 \mathcal{G}(X_t(j))dj = 1, \tag{16}$$

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

The profit maximisation problem of the perfectly competitive goods bundler gives way to the relative demand for the product of firm z:

$$X_t(j) = \tilde{\mathcal{G}} \left(\frac{P_t(j) Y_t}{v_t} \right) \tag{17}$$

where $\tilde{\mathcal{G}} \equiv \mathcal{G}'^{-1}(.)$ and v_t is multiplier of the constraint in the Lagrangean representation of this maximisation problem.

The price deflator can be implicitly defined by

$$P_t Y_t = \int_0^1 P_t(j) Y_t(j) dj$$

and

$$v_t = P_t Y_t \left(\int_0^1 \mathcal{G}' \left(X_t(j) \right) X_t(j) dj \right)^{-1}.$$

Let us define the price elasticity of demand by

$$\Xi(X_t(j)) \equiv -\frac{\mathcal{G}'(X_t(j))}{\mathcal{G}''(X_t(j)) X_t(j)}.$$

In the special case when

$$\mathcal{G}(X_t(j)) = [X_t(j)]^{\frac{\varepsilon_p - 1}{\varepsilon_p}},$$

equation (16) boils down to the usual Dixit-Stiglitz aggregator which implies constant elasticity of substitution: $\Xi(X_t(j)) = \varepsilon_p$ for all $X_t(j)$ (Woodford (2003)). In the standard Dixit-Stiglitz case the demand function can be written as

$$X_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\varepsilon_p},$$

where the price index is defined as:

$$P_t \equiv \left(\int_0^1 [P_t(j)]^{1-\varepsilon_p} \, dj \right)^{1/(1-\varepsilon_p)}.$$

In the general Kimball case the own price elasticity of the elasticity of demand can be defined as

$$\epsilon(X_t(j)) \equiv \frac{\partial \Xi(X_t(j))}{\partial P_t(j)} \frac{P_t(j)}{\Xi(X_t(j))},$$

where in steady-state $\epsilon(1) = \epsilon > 0$ i.e. the elasticity declines if the firm sells more or, equivalently, elasticity is increasing in the price (Furlanetto and Seneca (2009)).

Intermediary firm z that last reset its price at time $T = 0$ maximises its present and discounted future profits with the probability of not resetting its price:

$$\max_{p_t^*} \sum_{T=0}^{\infty} (\xi^p \beta)^T \Lambda_{t,t+T} \left[p_{t+T}^*(j) Y_{t+T}(j) - TC\left(Y_{t+T}(j)\right) \right],$$

where p_t^* is the optimal reset price at time$-t$, ξ^p is the probability of not resetting the price, TC stands for the total cost of production and $\Lambda_{t,t+T}$ is the stochastic discount factor defined as:

$$\Lambda_{t,t+T} \equiv \beta \left(\frac{C_{t+T}^o - h_o C_{t+T-1}^o}{C_{t+T}^o - h_o C_{t+T+1}^o} \right)^{\sigma} \frac{P_t}{P_{t+T}}.$$

This firm's maximisation problem is subject to the production function in equation (15) and to the demand function of good z in equation 17.

The first order condition with respect to $p_t^*(z)$ is given by:

$$\sum_{T=0}^{\infty} (\xi^p)^T E_t \left\{ \Lambda_{t,t+T} Y_{t+T}(j) \left[p_t^*(1 - \Xi(X_t(j))) - \Xi(X_t(j)) P_{t+T} S_{t|t+T}(j) \right] \right\}, \tag{18}$$

where $S_{t|t+T}(j)$ is the time $t+T$ real marginal cost of firm j that last changed its price at time t.

The cost minimisation problem of the intermediary yields the demand for labor, the demand for capital and the marginal cost respectively:

$$W_t(j) = S_t(j)(1-\alpha) \frac{Y_t(j)}{N_t(j)}, \tag{19}$$

$$R_t^k(j) = S_t(j) \alpha \frac{Y_t(j)}{\mathcal{U}_t K_{t-1}(j)}, \tag{20}$$

$$S_t(j) = \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)} \left[R_t^k(j) \right]^{\alpha} [W(j)]^{1-\alpha}, \tag{21}$$

which—after aggregation and imposing symmetric equilibrium—can be expressed in their linear form, respectively, as:

$$w_t = s_t + y_t - n_t,$$

$$r_t^k = s_t + y_t - k_{t-1} - u_t,$$

$$s_t = \alpha r_t^k + (1-\alpha) w_t,$$

where s_t stands for the *average* real marginal cost.

The evolution of the aggregate price level in the Calvo model is given by:

$$P_t \equiv \left[(1-\xi^p)\,(p_t^*)^{1-\varepsilon_p} + \xi^p P_{t-1}^{1-\varepsilon_p} \right]^{1/(1-\varepsilon_p)}.$$

The loglinear version of equation (18) is the so-called new-Keynesian price Phillips curve:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa s_t, \tag{22}$$

where

$$\kappa \equiv \frac{(1-\xi^p)(1-\beta\xi^p)}{\xi^p} \frac{1}{1+\mathcal{I}\frac{\epsilon}{1-\varepsilon_p}}, \tag{23}$$

where $\mathcal{I}$ is an indicator variable that can take on the value of one or zero. When $\mathcal{I} = 1$ the model contains real rigidity in the form of Kimball (1995) demand. In Experiment **one** (see below) which utilises the above model without wage stickiness, habit formation and endogenous capital accumulation real rigidity is necessary because it helps to avoid a non-uniqueness problem (for more on this see footnote (21)). Experiment **five** which contains a model with capital also employs Kimball preferences. In the robustness analysis section we further elaborate on the importance of strategic complementarity[14].

1.3 Unions

To introduce wage stickiness into the model one usually assumes that households have monopoly power in determining their wage as in Erceg et al. (2001) who presume that each household can engage in perfect consumption smoothing. However, the presence of ROT households who cannot engage in intertemporal trade precludes the possibility of consumption smoothing. To motive a wage-setting decision we suppose following Gali et al. (2007) and Furlanetto and Seneca (2009) that there are a continuum of unions (on the unit interval), $z \in [0,1]$, each representing a continuum of workers of which a fraction (λ) are members of rule-of-thumb and the remaining $(1-\lambda)$ fraction consists of optimising households. Each union employs one particular type of labor (independently of the type households they originate from) that is different from the type of labor offered by other unions.

Each period the union maximises the weighted current and discounted future utility of its members:

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

subject to the labor demand function for labor of type z:

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

[14]See also Kaszab (2011) who found that strategic complementarity can change the magnitude of fiscal multipliers.

where $W_t(z)$ is the nominal wage set by the union z, ε_w is the elasticity of labor demand and W_t is an aggregate of the wages set by unions:

$$W_t \equiv \left(\int_0^1 [W_t(z)]^{1-\varepsilon_w} \right)^{\frac{1}{1-\varepsilon_w}}.$$

We follow Furlanetto (2011) in assuming that wage adjustments are costly and evolve similarly to Rotemberg (1982) who originally applied it to model price adjustment. In particular, there is a wage adjustment cost which is a quadratic function of the change in the nominal wage and proportional to the aggregate wage bill. The presence of this wage adjustment cost is justified by the fact that unions have to negotiate wages each period and this activity consumes real resources. The larger is the increase in nominal wage achieved by the union the higher is the effort associated with it. Each union members incurs an equal share of the wage adjustment cost. Thus, the nominal membership fee, F paid by a generic union member 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 ϕ_w governs the size of the adjustment costs. In the special case of $\phi_w = 0$ the model coincides with the one in Gali et al. (2007).

The first-order condition associated with the union's problem is the same as the one in Furlanetto (2011):

$$\begin{aligned} 0 \;=\; & \left(\lambda \frac{\partial U_t^r}{\partial C_t^r} + (1-\lambda) \frac{\partial U_t^o}{\partial C_t^o} \right) (1-\tau_{m,t}^l) \tilde{W}_t [(\varepsilon_w - 1) + \phi_w (\Pi_t^w - 1) \Pi_t^w] - \varepsilon_w N_t^{\varphi} \\ & -\beta \left[\left(\lambda \frac{\partial U_{t+1}^r}{\partial C_{t+1}^r} + (1-\lambda) \frac{\partial U_{t+1}^o}{\partial C_{t+1}^o} \right) \right] \phi_w (\Pi_{t+1}^w - 1) \Pi_{t+1}^w \frac{W_{t+1}}{P_{t+1}} \frac{N_{t+1}}{N_t}, \end{aligned} \tag{24}$$

where $\Pi_t^w \equiv W_t/W_{t-1}$ is the wage inflation, $\tilde{W}_t \equiv W_t/P_t$ is the real wage and $\frac{\partial U_t^i}{\partial C_t^i}$ is defined by equation (5) for $i \in \{o, r\}$. The marginal tax rates of labor differ between the two types of households and, hence the aggregate marginal tax rate is defined as $\tau_{m,t}^l = \lambda \tau_{m,t}^{l,r} + (1-\lambda) \tau_{m,t}^{l,o}$ with $\tau_{m,t}^{l,r}$ and $\tau_{m,t}^{l,o}$ denoting the marginal tax rates of labor for non-Ricardian and Ricardian households, respectively. The consumption also differs between the two types of consumers. When making a decision on labor demand the firm does not distinguish between different workers of type z. Thus, in the aggregate, $N_t^r = N_t^o = N_t$ holds i.e. they work the same amount of hours. The linearisation of equation (24) yields what we call the new-Keynesian wage Phillips curve:

$$\pi_t^w = \beta E_t \pi_{t+1}^w - \kappa^w \left[w_t - mrs_t - \chi \hat{\tau}_{m,t}^l \right], \tag{25}$$

where $\pi_t^w \equiv \log(\Pi_t^w/\Pi^w)$, $w_t \equiv \log(\tilde{W}_t/\tilde{W})$, $\hat{\tau}_{m,t}^l \equiv \tau_{m,t}^l - \tau_m^l$, $\kappa^w \equiv \frac{\varepsilon_w - 1}{\phi_w}$[15] and the linearised expression for the marginal rate of substitution is[16]:

$$mrs_t = \chi_r (c_t^r - h_r c_{t-1}^r) + \chi_o (c_t^o - h_o c_{t-1}^o) + \varphi n_t, \tag{26}$$

[15] In calculating the value of κ^w we use $\frac{(1-\xi^w)(1-\beta\xi^w)}{\xi^w} \frac{1}{1+\varphi \frac{\varepsilon_w}{\varepsilon_w - 1}}$ which results in case of Calvo wage setting and equivalent to $\frac{\varepsilon_w - 1}{\phi_w}$ that we obtain under Rotemberg wage setting.

[16] Note that we assume a tax policy that equates steady-state consumptions across household types (i.e., $C^r = C^o$).

where

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

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

Note that in case of $h_o = h_r = 0$ equation (26) boils down to the case of CRRA utility without habits. Without loss of generality we postulate, following Furlanetto and Seneca (2012), that $h_r = h_o = h$ implying $\chi_r \equiv \lambda/(1-h)$ and $\chi_o \equiv (1-\lambda)/(1-h)$. The connection between the wage inflation (π_t^w), price inflation (π_t) and the real wage (w_t) can be expressed, in linear form, as:

$$\pi_t^w = w_t - w_{t-1} + \pi_t. \tag{27}$$

1.4 Fiscal and Monetary Policy

1.4.1 Fiscal policy

Similarly to Christiano (2010) and Christiano et al. (2011) we consider a deterministic experiment: the tax rate is cut with the same amount in each period for the entire duration of the shock.

Government raises revenues in the form of an income tax. We abstract from the possibility of lump-sum taxation. The government's budget is balanced every period:

$$P_t G_t = \tau_t (W_t N_t + R_t^k K_t) + T,$$

where $\tau_t = \gamma \tau_t^{l,r} + (1-\gamma)\tau_t^{l,o}$ and T are the sum of lump-sum taxes collected from each type of household. Without loss of generality we used the shortcut by Guo and Lansing (1998) in assuming that the wage and capital revenues are taxed at the same rate, $\tau_t^{l,o} = \tau_t^{l,r} = \tau_t^k = \tau_t$. However, we found our main result to remain valid if different tax rates are applied for capital and labor (these experiments are not reported here).

The average tax rate schedule follows the formulation in Guo and Lansing (1998) and Mattesini and Rossi (2012):

$$\tau_t = 1 - \eta \left(\frac{Y_n}{Y_{n,t}} \right)^{\phi_n}, \ \eta \in (0,1], \ \phi_n \in [0,1), \tag{28}$$

where $Y_{n,t} = \lambda Y_{n,t}^r + (1-\lambda) Y_{n,t}^o$. In the latter expression $Y_{n,t}^r = W_t N_t / P_t$ is the income of non-Ricardians while $Y_{n,t}^o = W_t N_t / P_t + R_t^k K_t / P_t$ is the actual income of optimisers (both of them in real terms). Here, Y_n is the steady-state value of $Y_{n,t}$. The wage income $W_t N_t$ is the wage income of each type of household while capital income $R_t^k K_t$ belongs solely to the Ricardians. The parameters η and ϕ_n govern the level and the slope of the tax schedule, respectively. Provided that $\phi_n > 0$ households with taxable income $Y_{n,t}$ higher than steady-state actual income Y_n experience higher tax rates τ_t. When $\phi_n = 0$ all households face the same flat tax rate irrespectively of their taxable income. We do not consider the case of $\phi_n < 0$ which is called regressive regressive tax schedule. Parameters η and ϕ_n are chosen to ensure $0 \le \tau_t < 1$ and, thus, households have an incentive to supply labour to firms.

Progressivity of the taxation can be better understood by making a distinction between the average tax rate, which is given by (28) and the marginal tax rate $\tau_{m,t}$ which is derived as:

$$\tau_{m,t} = \frac{\partial(\tau_t Y_{n,t})}{\partial Y_{n,t}} = 1 - \eta(1-\phi_n)\left(\frac{Y_n}{Y_{n,t}}\right)^{\phi_n}, \tag{29}$$

We combine equation (28) and (29) to obtain

$$\tau_{m,t} = \tau_t + \eta\phi_n\left(\frac{Y_n}{Y_{n,t}}\right)^{\phi_n} \tag{30}$$

which shows that $\tau_{m,t}$ is always higher than τ_t. The loglinear version of equation (30), $\hat{\tau}_{m,t} = \hat{\tau}_t - \eta(\phi_n)^2\hat{y}_{n,t}$, with $\hat{y}_{n,t} \equiv \log(Y_{n,t}/Y_n)$ is included among our equilibrium conditions.

1.4.2 Monetary Policy

Monetary policy is described by the rule in Christiano et al. (2011):

$$R_t = \max(Z_t, 0) \tag{31}$$

where

$$Z_t = (1/\beta)(1+\pi_t)^{\phi_1(1-\rho_R)}(Y_t/Y)^{\phi_2(1-\rho_R)}[\beta(1+R_{t-1})]^{\rho_R} - 1, \tag{32}$$

where Z_t is the shadow nominal interest rate which can take on negative values as well. As usual, we assume that $\phi_1 > 1$, $\phi_2 \in [0,1)$ and $0 < \rho_R < 1$. ϕ_1 controls how strongly monetary policy reacts to changes in inflation while ϕ_2 governs the strength of the response of nominal interest to changes in output-gap[17]. The main implication of the rule in equation (31) is that whenever the nominal interest rate becomes negative, the monetary policy set it equal to zero, otherwise it is set by the Taylor rule specified in equation (32). The parameter ρ_R measures how quickly monetary policy reacts to changes in inflation and output-gap. Furthermore, inflation in steady-state is assumed to be zero which implies that steady-state net nominal interest rate is $1/\beta - 1$.

The monetary policy rule above can be written, in linear form, as:

$$dR_t = \begin{cases} dZ_t, & dZ_t \geq -\left(\frac{1}{\beta}-1\right), \text{ 'zero bound not binding'} \\ -\left(\frac{1}{\beta}-1\right), & \text{otherwise}, \qquad \text{'zero bound binding'} \end{cases},$$

$$dZ_t = \rho_R dR_{t-1} + (1-\rho_R)\frac{1}{\beta}\left[\phi_1\pi_t + \phi_2 y_t\right].$$

Hence, the ZLB on the nominal interest binds when $dR_t = -\left(\frac{1}{\beta}-1\right)$. Otherwise, we set $dR_t = dZ_t$.

[17]Precisely, the term Y_t/Y does not stand for the output gap as the definition of the output gap contains the deviation of the actual GDP from its flexible price level equivalent. Here we simply use the deviation of output from its steady-state value.

1.5 Aggregation, Market Clearing and Equilibrium

The aggregate consumption and hours worked is a composite of those of the two types of households:

$$C_t = \lambda C_t^r + (1-\lambda)C_t^o,$$

$$N_t = \lambda N_t^r + (1-\lambda)N_t^o.$$

The aggregate capital, investment and dividend payments is determined by $K_t = (1-\lambda)K_t^o$, $Inv_t = (1-\lambda)Inv_t^o$ and $D_t = (1-\lambda)D_t^o$.

The aggregation equation with the assumption of consumption and hours of different types of households are equal in steady-state:

$$c_t = \lambda c_t^r + (1-\lambda)c_t^o,$$

$$n_t = \lambda n_t^r + (1-\lambda)n_t^o,$$

which is obtained by setting steady-state consumption and hours worked of each type equal in steady-state ($C^r = C^o$ and $N^r = N^o$) using a lump-sum tax (see the previous discussion in the section describing Ricardian households).

The presence of unions implies that every household work the same number of hours and, thus, $n_t^r = n_t^o = n_t$ for all t.

The goods market clearing is

$$Y_t = C_t + Inv_t + G_t + \Omega(\mathcal{U}_t)K_{t-1},$$

which can be expressed in linear form as

$$y_t = \gamma_c c_t + \gamma_i inv_t + g_t + \gamma_k R^k u_t,$$

where for the rest of the paper we set $g_t = 0$ and γ_c is calculated as described in Appendix B of Gali et al. (2007):

$$\gamma_c = 1 - \gamma_i - \gamma_g = 1 - \frac{\delta\alpha}{\alpha(Y/K)} - \gamma_g = 1 - \frac{\delta\alpha}{\mu^p(\rho+\delta)} - \gamma_g,$$

where $\gamma_c \equiv C/Y$, $\gamma_i \equiv I/Y$, $\gamma_g \equiv G/Y$, $\gamma_k \equiv K/Y$ and the last equality made use of the fact that in steady-state $R^k = \alpha Y/\mu^p K = \alpha/(\gamma_k\mu^p)$ which assumes that the steady-state marginal cost is constant and equal to the inverse of the markup defined as $\mu^p \equiv \varepsilon_p/(\varepsilon_p - 1)$. The steady-state rental rate is $R^k = \rho + \delta$ with $\rho \equiv \beta^{-1} - 1$. In steady-state $\Omega(\mathcal{U}_t)K_{t-1}$ term disappears because of $\mathcal{U} = 1$ and $\Omega(1) = 0$.

Definition 1 *After having outlayed the building blocks we are ready to define equilibrium of this model. The equilibrium is characterised by a sequence of endogenous quantities*

$$\{K_t, N_t^o, N_t^r, N_t, C_t^o, C_t^r, C_t, Inv_t, \mathcal{U}_t, Y_t, B_t\}_{t=0}^{\infty},$$

price sequences

$$\{Q_t, \Pi_t, \Pi_t^w, R_t^k, W_t, S_t, R_t, Z_t, \tau_{m,t}\}_{t=0}^{\infty},$$

and a given set of exogenous deterministic shocks

$$\{R_t^{\text{real}}, \tau_t\}_{t=0}^{\infty}$$

and initial values for the state variables (capital and debt) that satisfy equilibrium conditions of the household, firms, unions, government and monetary authority such that markets clear, the transversality conditions for the endogenous states are imposed and the aggregate resource constraint is also satisfied.

2 Calibration

Households. The discount factor, β, is equal to 0.99 implying a real annual interest rate of 4%. The elasticity of intertemporal substitution, σ, is set to one implying log utility which is usual in the literature. Following Christiano (2010 and see the references therein) the parameter governing the disutility of labor, φ is chosen to be one (i.e. Frisch elasticity of labor supply, $1/\varphi$, is also one) which is more conservative than the value of 0.2 used by Gali et al. (2007). Also, similarly to Christiano (2010) we use $\varepsilon_p = \varepsilon_w = 6$. For habit formation parameter, h, Furlanetto and Seneca (2011) set a high value of 0.85 while Smets and Wouters (2007) employing a model with various frictions estimate a value of 0.6. Therefore, we consider a value in the middle range and set $h = 0.7$.

The steady-state government spending-GDP ratio, γ_g, is set to 0.2 mimicking the post-war US evidence. Thus, for variants of the baseline model setup without capital we set steady-state consumption-income ratio, γ_c, to 0.8. In our full model with capital the investment-GDP and consumption-GDP ratios are implied by the deep parameters and γ_g. Furlanetto and Seneca (2009) calibrates the share of rule-of-thumb consumers (λ) to be between 29% and 35% after reviewing a couple of econometric studies. Based on this we set $\lambda = 0.3$ which we think is more plausible empirically than the 0.5 used by Gali et al. (2007).

Monetary Policy. The inflation coefficient in the Taylor rule, ϕ_1, is 2. Following Christiano (2010) and Christiano et al. (2011) there is neither interest-rate smooting ($\rho_R = 0$) nor response to output gap in the Taylor rule ($\phi_2 = 0$).

Fiscal Policy. The steady-state labor tax rate (τ) is chosen to be 30% as in Christiano (2010). The size of the discount factor shock, r_t, is set to -0.0104 which is the mode of the estimation by Denes and Eggertsson (2010) using a model that contains only price rigidity and specific labor market. The duration of the negative demand shock is 10 periods[18] which is in accordance with the modal estimate of Denes and Eggertsson (2009). η is calibrated such that $1 - \eta$ equals the steady-state labor tax rate. Mattesini and Rossi (2012) calculates ϕ_n for a number of OECD countries and obtains a value of 0.18 for the United States.

Firms. The benchmark value of Christiano, Eichenbaum and Evans (2005) for Ω_u is 0.01. The depreciation rate of capital is a standard choice: 0.025 at a quarterly rate. The mean posterior estimates of Smets and Wouters (2007) for the Calvo parameters, $\xi^p = 0.66$ ($\xi^w = 0.7$) imply an average price (wage) stickiness of around two (three) quarters. The reduced

[18] Eggertsson (2010) and Denes and Eggertsson (2009) consider a stochastic experiment with a persistence estimate of $\mu = 0.9030$ for the discount factor shock process. This μ is easily translated into our deterministic experiment knowing that the average duration of this AR(1) is $1/(1-\rho)$ which is roughly 10. For a similar argument see Appendix C of Carlstrom, Fuerst and Paustian (2012).

form estimates (see for references Furlanetto and Seneca (2009)) on the new-Keynesian price Phillips curve imply $\kappa = 0.03$. Without real rigidity such a value of κ would imply a very long-period of price inertia ($\xi^p = 0.85$). In our baseline calibration without real rigidity (i.e. $\mathcal{I} = 0$) $\xi^p = 0.66$ implies $\kappa = .1786$. When $\mathcal{I} = 1$ the calibration of $\kappa = 0.03$ is achieved by setting an appropriate value for ϵ. The implied value of ϵ is 24.77 which is in the range of empirical estimates listed in Furlanetto and Seneca (2009).

3 Experiments

Our experiments are in the spirit of Christiano (2010) and Christiano et al. (2011)[19] who assumed that the discount factor shock and the corresponding fiscal policy shock is on for a deterministic period of time. The deterministic simulations are executed using the codes of Christiano (2010) and Christiano et al. (2011)[20]. In particular, their codes implement a standard shooting algorithm to handle the ZLB problem. The details of this algorithm are available in the appendix of Christiano (2010).

The zero lower bound experiments resemble the ones in Christiano (2010). A discount factor shock hits the economy in period one. The model is in deterministic steady-state until $t = 1$. At $t = 1$ the discount rate drops from its steady-state value of 0.01 (per quarter) to $r = -0.01$ and remains low for $T = 10$ quarters[21]. From quarter 11 ($T + 1$) on the discount rate is back to its steady-state value. Note that all the deterministic experiments below assume that the discount factor shock is on for ten periods although its size slightly varies across them.

The steady-state level of labor tax is 30 per cent ($\tau = 0.3$). In the no policy response simulation the labor tax rate is at its steady-state level for the entire simulation. In the alternative simulation (denoted with dashed line) the labor tax rate is decreased (in contrast to Christiano (2010) and Christiano et al. (2011) who considered a rise in the tax rate) to 20 per cent for the time period in which the zero lower bound on the nominal interest rate is binding. The shooting algorithm determines endogenously the date at which the zero lower bound becomes binding and the date at which the zero lower bound ceases to bind. We conduct five experiments and the elements of the models used in each experiment is listed in Table (1).

Figure 1 shows[22] the **first** experiment featuring a model that includes two types of house-

[19] Note that section 2 and 3 of Christiano et al. (2011) consider a stochastic experiment similar to those in Eggertsson (2010) and Woodford (2010) while section 4 and 5 consider deterministic experiments that are accomplished by using a standard shooting algorithm. In case of only price rigidity (or only wage riditiy) the system can be re-written using the Eggertsson-Woodford (2003) type of methodology applicable if the system contains no state variable. The latter is not true any more in case of the inclusion of both price and wage stickiness when one of the variables (potentially the real wage) becomes an endogenous state. Hence, we make use of the shooting algorithm of Christiano (2010).

[20] The codes are available from Lawrence Christiano's website.

[21] For comparison, Christiano (2010) considered a shock of similar size although a somewhat longer period ($T = 15$).

[22] Consumption (both ROT and OPT), hours, output, investment, real wage rate are expressed as percentage deviation from their steady-state values (on the graphs it is indicated as "% deviation from ss") while price inflation, wage inflation, shadow interest rate, nominal and real interest rate is express az annual percentage rate (APR).

holds and price rigidity. In the first experiment we assume that there are neither endogenous capital (i.e. equations (11), (12) and (13) are eliminated) nor wage stickiness in the economy i.e. the wage Phillips curve in equation (25) is removed). Therefore, wages are flexible in experiment one[23]. In the absence of tax policy the ZLB ends in period 6 while the presence of tax policy makes the ZLB bind for 9 periods. The tax cut magnifies the deflationary effects described by Eggertsson (2010a): the price deflation and the contraction in hours are more severe with the tax cut. Also note that the drop in real wage—which equals to the marginal cost due to constant returns assumption—is considerable. The consumption falls for both types of households. Hence, the wage tax cut does not alleviate the negative consequences of the savings shock (huge deflation and fall in output). In fact, the labor tax cut makes the zero lower bound even more binding. When zero lower bound ceases to bind the Taylor rule becomes operational and monetary policy reacts to expansionary fiscal policy (i.e. the labor tax cut) by raising the nominal interest rate. Hence, there is a large upward movement in nominal interest following the zero lower bound period. Also it it well known that the inclusion of the Taylor rule in one of the regimes guarantees determinacy in the other regime characterised by fixed interest rate (see, among others, Carlstrom et al. (2012)).

Figure 2 shows an experiment similar to the first one but this time we introduce wage stickiness into the model (**second** experiment). The discount rate is set to -0.01 per quarter. The ZLB binds for period 1 to 6 (7) without (with) policy. Wages are set by unions and assumed to remain fixed for about 3 quarters. Again we operate with a simple fiscal scenario: the wage tax cut is backed by current and future rise in lump-sum taxes paid by Ricardian agents. In this particular case OPT internalise the government budget constraint. The wage tax cut increases the disposable income of ROT households who consume it. In the absence of policy change the real wage does not fall dramatically due to the presence of wage stickiness in sharp contrast to the previous experiment. But still the tax cut remains deflationary (as the labor supply shifts to the right) and the real wage in the case of tax policy falls more than without policy. Observing the graphs we can also see that the wage deflation is higher than the price deflation implying a fall in the real wage rate. With perfect wage-stickiness (ξ^w is close to one)—which is not the case here but serves as a useful abstraction (see e.g. the argument of Christiano (2010))—the labor supply would remain inact. In the next we analyse the indirect reaction of labor demand to the tax cut.

The higher consumption demand of non-Ricardian agents induces many of the firms which cannot charge a higher price due to price stickiness to increase their production. To produce more firms demand more labor i.e. the labor demand shifts out. As it is well-known in sticky-price models a rise in aggregate demand—due to the higher consumption expenditures of ROT households—leads to a fall in the markup, which induces an outward shift in the

[23] In this experiment we found numerically that there are two solutions to the shooting problem (hence no unique solution). Also we realised that the drop in output and inflation is extremely large in this simplest variant of model (without capital, habits and wage rigidity) containing two types of households. The indeterminacy problem in the baseline Gali et al. (2007) model for even empirically reasonable calibrations is well-known in the literature. The zero-lower bound channel adds some further complication, namely, the zero lower bound on the nominal interest rate has to be binding. To avoid the non-uniqueness problem and to reduce the extreme negative impact of the shock we introduce strategic complementarity into price setting in the way discussed above. As Ascari et al. (2011) argues the uniqueness problem is mitigated by the inclusion of wage rigidity into the baseline model. Thus, in the models containing wage rigidity we do not encounter such non-uniqueness problem.

labor demand. Below we discuss the reaction of labor supply following the tax cut.

In our model the labor supply decision is relegated to unions whose members are supposed to work the same number of hours. Ascari et al. (2011) shows that a rightward shift in the labor demand triggers a large reaction in hours worked and small change in real wage in a model with wage-stickiness with the opposite being true—i.e. wage moves more than hours—when wage is completely flexible. As a result of the negative wealth effect of the labor tax cut Ricardians demand less consumption good and also less leisure time. As the time frame is normalised to one, the fall in leisure time implies spending more time working. Due to the tax cut Ricardians receive more money after each hour worked and, thus, they are induced to increase their labor supply. Because of the unions non-Ricardians work the same number of hours as Ricardians. Thus, both Ricardians and non-Ricardians satisfy higher demand for labor by working more.

It is important to discuss how much progressive taxation contributes to our result. The parameter governing the strength of the response of the tax rate to income, ϕ_n, is calibrated to a low value implying mildly progressive taxes. Generally, progressive taxation is aimed to achieve an egalitarian distribution of income, that is, a low marginal tax rate is associated with a lower than average income. However, in our model progressive taxation has another advantage. The heavy fall in output following the discount factor shock leads to a rise in the average tax rate due to the progressive scheme and, thus, the negative effects of the demand shock are mitigated to some extent.

The **third** experiment shown on Figure 3 makes use of the model in the previous simulation but now it includes external habit formation in consumption as well. Due to the lagged consumption term habit formation injects some endogenous persistence into the model and leads to hump-shaped impulse responses in OPT consumption and hours. Habit formation is a well-known feature of middle-sized DSGE models like the one of Smets and Wouters (2007) and is found useful in matching the empirical VAR evidence. Also habit formation is usually regarded to have some solid psychological foundation. The presence of habits mitigates the negative effects of the shock. This can be explained as follows. As argued above it is the rise in the real interest that makes people delay their consumption expenditure. The introduction of habits reduces the sensitivity of consumption to changes in the real interest (this can be quickly verified by looking at equation (10) where the coefficient on the interest is smaller in case of habits $[\frac{1-h_o}{1+h_o}\frac{\beta}{\sigma}]$ than it is for the standard CRRA case $[\beta/\sigma]$). To generate a fall in variables of magnitude similar to the those in the previous experiments we consider a somewhat bigger drop in the discount factor (-0.03). The ZLB binds from period 1 to 8 (10) without (with) policy. Still output (hours) declines less when labor tax cut policy is applied.

In the **fourth** experiment on figure 4 we add endogenous capital accumulation preserving all the other previous properties *but abstracting from habit formation*. Here we set the size of the discount factor shock to -0.015. The ZLB binds for periods 1 to 8 (7) with (without) policy. Again output, consumption and hours fall less when there is a cut in the labor tax. Now there is one more channel, notably investment, that supports the favorable effect of tax decrease beyond the positive response of ROT consumption. However, the positive effects of the tax cut on investment are less apparent in the short-run because of the investment adjustment costs. As Monacelli and Perotti (2008) argues the investment is inertial in the short run i.e. it exhibits no response at the beginning and builds up only gradually. The most interesting feature of this experiment is that wage deflation under the labor tax cut is smaller than in the absence of policy. Hence, the real wage (and also the rental rate on capital) can increase to some extent after the labor tax cut (in other words, it falls by less under the wage tax cut policy scenario relative to the case of no policy change). This finding appears to be quite counterintuitive at the first sight and can be explained as follows.

The negative demand shock in the zero lower bound environment leads to a jump in the real interest rate. In equilibrium the rental rate on capital and the real interest earned on risk-free bonds are equated. Thus, the higher real interest is coupled with higher rental rate which, through equation (21), elevates the marginal cost. The surge in marginal cost generates inflation through the new-Keynesian Phillips curve. Therefore, the inclusion of physical capital makes the tax cut policy even more effective in the sense that the tax cut generates a rise in marginal cost and inflation through the increase in the rental rate.

In the **fifth** experiment on figure 5 we consider the setup in the fourth experiment with external habit formation, capital utilisation[24] and real rigidity induced by Kimball-demand setting $\mathcal{I} = 1$ in expression (23). The lower bound binds for 7 (9) periods without (with) labor tax cut policy. Several things are interesting in this graph. Note that the real wage cannot increase (or fall by less) in case of the tax cut policy anymore in this setting due to the presence of habit formation that slows down the reaction of consumption. In particular, the consumption of ROT consumers declines to higher extent relative to the model in the previous experiment and the resulting rightward shift in the labor demand is limited. Hence, the real wage cannot increase and the finding of Experiment 2-3 is reconfirmed. In the next we conduct some robustness checks.

4 Sensitivity checks

We also investigated how sensitive our results to changes in various parameter values using the model in experiment five. The main findings are not affected if there is a slight decrease/increase in the risk-aversion/inverse of the intertemporal elasticity of substitution (σ), Frisch elasticity ($1/\varphi$), substitution among goods and labour types (ε_p and ε_w) and Calvo parameters of the goods and labour market (ξ^p and ξ^w) ceteris paribus. The shape of the shadow nominal interest rate (Z_t) becomes hump-shaped after the introduction of interest rate smoothing. In particular, ρ_R is chosen to be the estimated value by Smets and Wouters (2007). The case of positive ρ_R has the peculiar feature of making the zero lower bound binding in the second period in contrast to simulations 1-5 when it always begins to bind in period one. In general, changes in any of the parameters might change the dates at which the zero lower bound starts/ceases to bind. Allowing for a positive coefficient on the output gap (ϕ_2) in the Taylor-rule do not have big effect on the impulse responses as the Taylor rule is effective after the zero lower bound period. These experiments are not reported in the paper although available on request.

[24]By employing capital utilisation we can mute the negative wealth effect of the labor tax cut on OPT households. As a result consumption and output will fall by less.

5 Conclusion

After augmenting the baseline new-Keynesian model containing price and wage rigidity with rule-of-thumb (or non-Ricardian) households we argued that a labor tax cut can partly offset the fall in output and deflation caused by a negative demand shock that made the zero lower bound on the nominal interest rate binding. Importantly, we assumed that we cut the labor tax rate that is levied upon the households and not upon the firms. Under such an arrangement the labor tax cut acts like a traditional fiscal stimulus that raises aggregate demand. Our results remain valid after the extension of the model with capital accumulation with variable utilisation, external habits in consumption and strategic complementarity in price setting. In a companion paper we study tax cuts that are financed by government debt and by distortionary taxes (instead of lump-sum taxes). It would be interesting to explore whether our result remains true in another popular model featuring monopolistic competition, which predicts that consumption rises after an increase in aggregate demand even without sticky prices—this is the deep habit model of Ravn, Schmitt-Grohe and Uribe (2006). Finally, rule-of-thumb consumers can be thought of as a shortcut of modeling agents with borrowing constraint. Based on the logic of the model with rule-of-thumb households our finding should remain valid in a model with savers and borrowers who face borrowing constraints.

References

[1] Altig, Christiano, Lawrence, Eichenbaum, Martin and Jesper Linde (2012) "Firm-Specific Capital, Nominal Rigidities and the Business Cycle," Review of Economic Dynamics, vol. 14 pp. 225-247.

[2] Ascari, Guido, Colciago, Andrea and Lorenza Rossi (2011) "Limited Asset Market Participation, Sticky Wages and Monetary Policy." mimeo, June.

[3] Bilbiie, Florin "Limited Asset Market Participation, Monetary Policy and (Inverted) Aggregate Demand Logic", Journal of Economic Theory, 2008, vol. 140(1), pp. 162-196.

[4] Bilbiie, Florin, Tomasso Monacelli and Roberto Perotti (2012a) "Public Debt Redistribution with Borrowing Constraints", mimeo.

[5] Bilbiie, Florin, Tomasso Monacelli and Roberto Perotti (2012b), "Tax Cuts vs. Spending Increases: Welfare at the Zero Lower Bound," mimeo. July.

[6] Florin, Bilbiie and Roland Straub (2004), "Asset Market Participation and Distortionary Taxation: Keynesian and Non-Keynesian Effects of Fiscal Policy", Hungarian National Bank Working Papers. and Reinvestment Plan," memo, The White House.

[7] Bils, Mark and Peter J. Klenow (2004), "Some Evidence on the Importance of Sticky Prices," Journal of Political Economy. October. 112, pp. 947-985.

[8] Braun, R. Anton, Lena Mareen Körber and Yuichiro Waki, 2012, "Some unpleasant properties of log-linearized solutions when the nominal rate is zero," February 15, unpublished manuscript, Federal Reserve Bank of Atlanta.

[9] Calvo, Guillermo (1983), "Staggered Prices in a Utility-Maximizing Framework," Journal of Monetary Economics 12, 383-398.

[10] Carlstrom, Charles, Timothy Fuerst, and Matthias Paustian (2012), "How Inflationary is an Extended Period of Low Interest Rates?," Federal Reserve Bank of Cleveland Working Paper.

[11] Chari V.V., Kehoe, Patrick Patrick J. and Elen McGrattan (2009),"New Keynesian Models: Not Yet Useful for Policy Analysis", American Economic Journal: Macroeconomics. 1:1, pp. 242-266.

[12] Chrisitano, Lawrence (2010), "Comment on Eggertsson, "What Fiscal Policy Is Effective at Zero Interest Rates?" ", NBER Macroeconomics Annual.

[13] Chrisitiano, Lawrence, Martin Eichenbaum and Sergio Rebelo (2010), "When is Government Spending Multiplier Large?" Journal of Political Economy. Vol. 119, No. 1, pp. 78-121. February.

[14] Chrisitiano, Lawrence and Martin Eichenbaum (2012), "Notes on Linear Approximations, Equilibrium Multiplicity and E-learnability in the Analysis of the Zero Lower Bound," mimeo. March.

[15] Chrisitiano, Lawrence, Martin Eichenbaum and Charles Evans (2005), "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," Journal of Political Economy. Vol. 113. No. 1.

[16] Coenen, Günter, Christopher J. Erceg, Charles Freedman, Davide Furceri, Michael Kumhof, René Lalonde, Douglas Laxton, Jesper Lindé, Annabelle Mourougane, Dirk Muir, Susanna Mursula, Carlos de Resende, John Roberts, Werner Roeger, Stephen Snudden, Mathias Trabandt, and Jan in't Veld. 2012. "Effects of Fiscal Stimulus in Structural Models." American Economic Journal: Macroeconomics, 4(1): 22-68.

[17] Cogan John F., Tobias Cwik, John B. Taylor and Volker Wieland (2010), "New Keynesian versus Old Keynesian Government Spending Multipliers," Journal of Economic Dynamics and Control, 34 (3), pp. 281-295.

[18] Colciago, (2011), "Rule-of-Thumb Consumers Meet Sticky Wages," Journal of Money Credit and Banking. Vol. 43, No. 2–3 (March–April)

[19] Denes, Matthew and G. Eggertsson (2009), "A Bayesian Approach To Estimating Tax and Spending Multipliers," New York Fed Staff Paper.

[20] Thorsten Drautzburg and Harald Uhlig (2011), "Fiscal Stimulus and Distortionary Taxation," NBER Working Papers 17111, National Bureau of Economic Research, Inc.

[21] Eggertsson, Gauti (2010a), "What Fiscal Policy is Effective at Zero Interest Rates?," NBER Macroeconomic Annual.

[22] Eggertsson, Gauti (2010b), "The Paradox of Toil." New York Fed Staff Report no. 433. March.

[23] Eggertsson, Gauti and Michael Woodford (2003), "The Zero Bound on Interest Rates and Optimal Monetary Policy". Brookings Papers on Economic Activity.

[24] Erceg, Christopher J., Henderson, Dale W. and Andrew T. Levin (2000), "Optimal monetary policy with staggered wage and price contracts," Journal of Monetary Economics, vol. 46: Iss. 2 pp. 281-313. October.

[25] Furlanetto, Francesco (2011), "Fiscal Stimulus and the Role of Wage Rigidity", Journal of Economic Dynamics and Control, Vo. 35 pp. 512–527.

[26] Furlanetto, Francesco and Martin Seneca (2009), "Fiscal Shocks and Real Rigidities," The B.E. Journal of Macroeconomics. Vol. 9: Iss. 1 (Topics), Article 2.

[27] Gali Jordi, Lopez-Salidó David and Javier Vallés (2007), "Understanding the Effect of Government Spending on Consumption," Journal of European Economic Association 5(1): pp. 227-270, March.

[28] Hall, Robert E. (2009), "By How Much Does GDP Rise If the Government Buys More Output?," Brookings Papers on Economic Activity.

[29] Leeper, Eric (1991), "Equilibria Under 'Active' and 'Passive' Monetary and Fiscal Policies," Journal of Monetary Economics. vol. 27. pp. 129-147.

[30] Nakamura, Emi and Ion Steinnsson (2008) "Five Facts about Prices: A Reevaluation of Menu Cost Models". Quarterly Journal of Economics. vol. 123(4), pp. 1415-1464, November.

[31] Natvik, Gisle (2008) "Government Spending Shocks and Rule-of-Thumb Consumers with Steady-State Inequality," Scandinavian Journal of Economics, forthcoming.

[32] Mertens, Karel and Morten Ravn (forthcoming), "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States, "American Economic Review.

[33] Monacelli, T. and R. Perotti (2008), "Fiscal Policy, Wealth Effects, and Markups", NBER WP 14584, December.

[34] Ravn, Morten, Stephanie Schmitt-Grohe and Martin Uribe (2006), "Deep habits," Review of Economic Studies. vol. 73. pp. 195-218.

[35] Smets, Frank and Rafael Wouters (2007) "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," The American Economic Review. June.

[36] Woodford, Michael (2003), "Interest and Prices: Foundations of a Theory of Monetary Policy." Princeton University Press.

[37] Woodford, Michael (2011), "Simple Analytics of the Government Expenditure Multiplier," American Economic Journal: Macroeconomics, 3(1), pp. 1–35. January.

Table 1: Details of the models used in experiment 1-5

	Features of the model used
Experiment 1	price rigidity
Experiment 2	price and wage rigidity
Experiment 3	price and wage rigidity, consumption habits
Experiment 4	price and wage rigidity, physical capital
Experiment 5	price and wage rigidity, consumption habits, physical capital, capacity utilisation and Kimball demand

All experiments contain both Ricardian and non-Ricardian households.

Figure 1: This is called Experiment 1 in the text. Z stands for the shadow nominal interest rate. The + signs indicates the date at which the zero lower bound on the nominal interest rate becomes binding and circles appear on the date at which the zero lower bound ceases to bind. ss means steady-state.

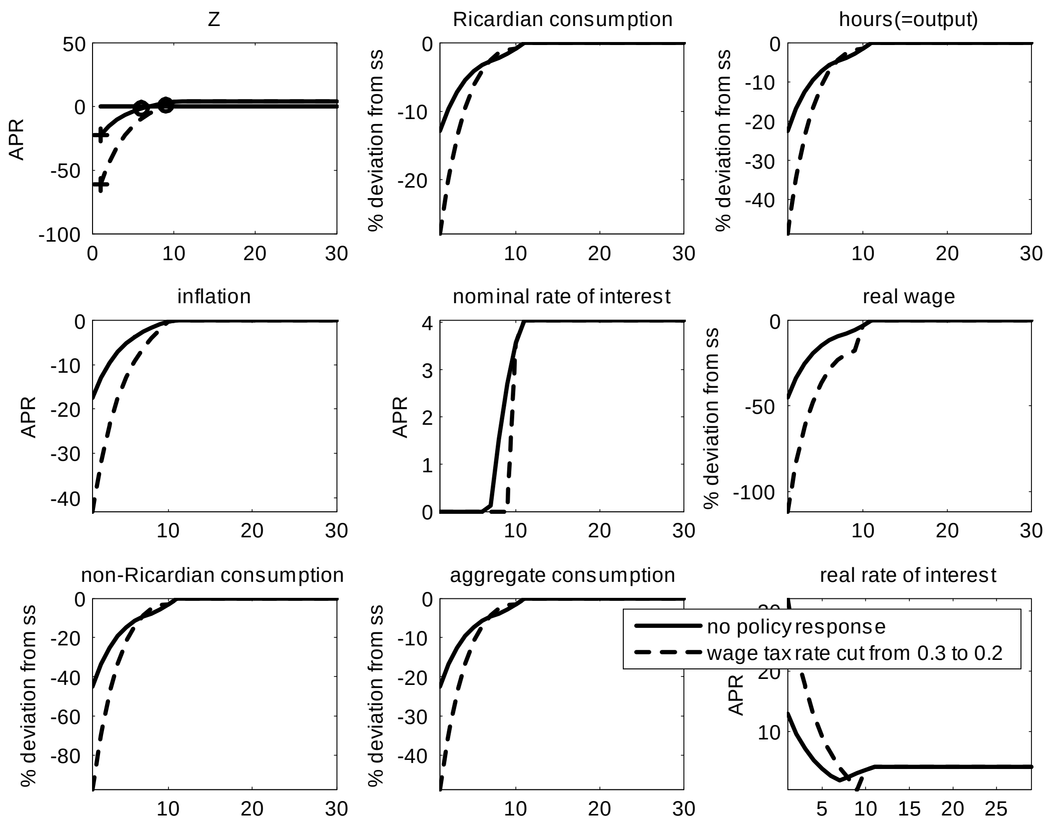

Figure 2: See details of Experiment 2 in the text. This is the model in Experiment 1 extended with wage rigidity.

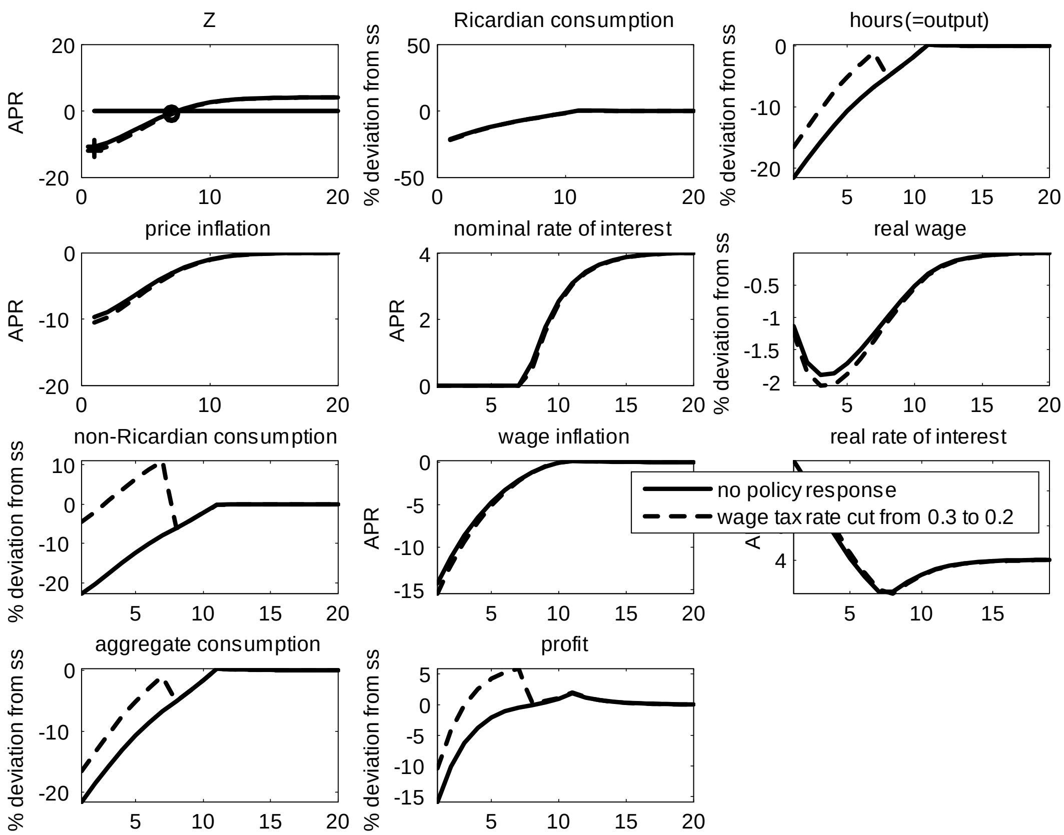

Figure 3: This is called Experiment 3 in the text. Here we used the model in Experiment 2 extended with external habit formation in consumption.

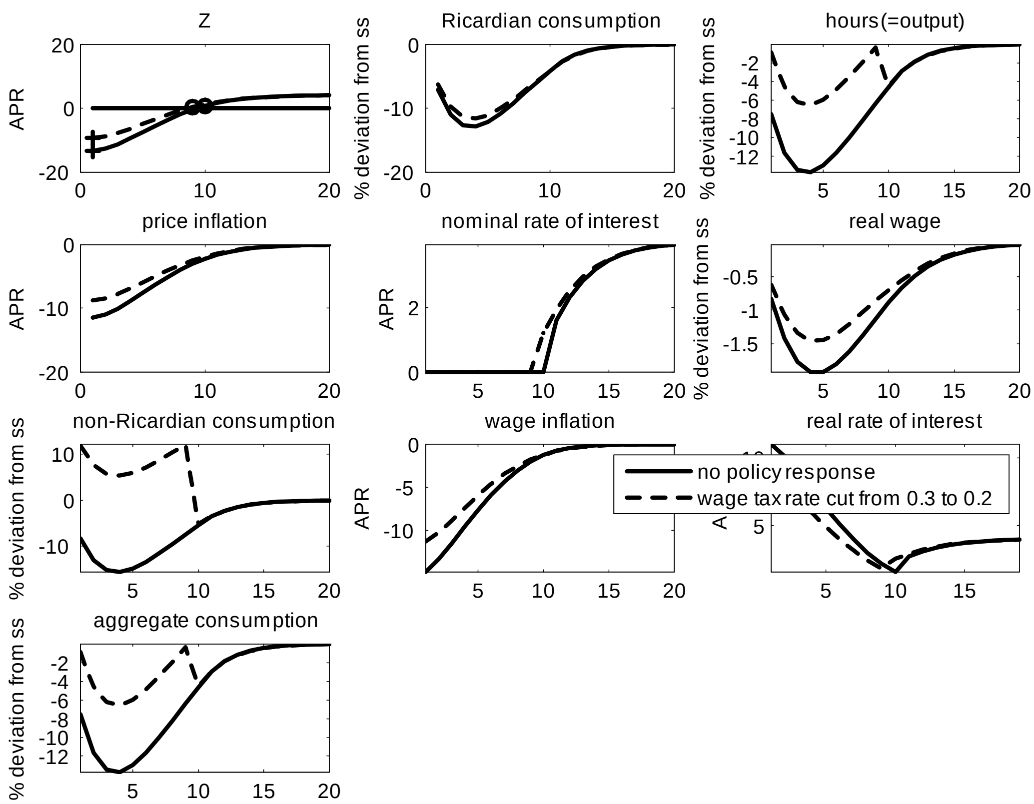

Figure 4: This is called Experiment 4 in the text. Here we used the model in Experiment 2 extended with endogenous capital accumulation.

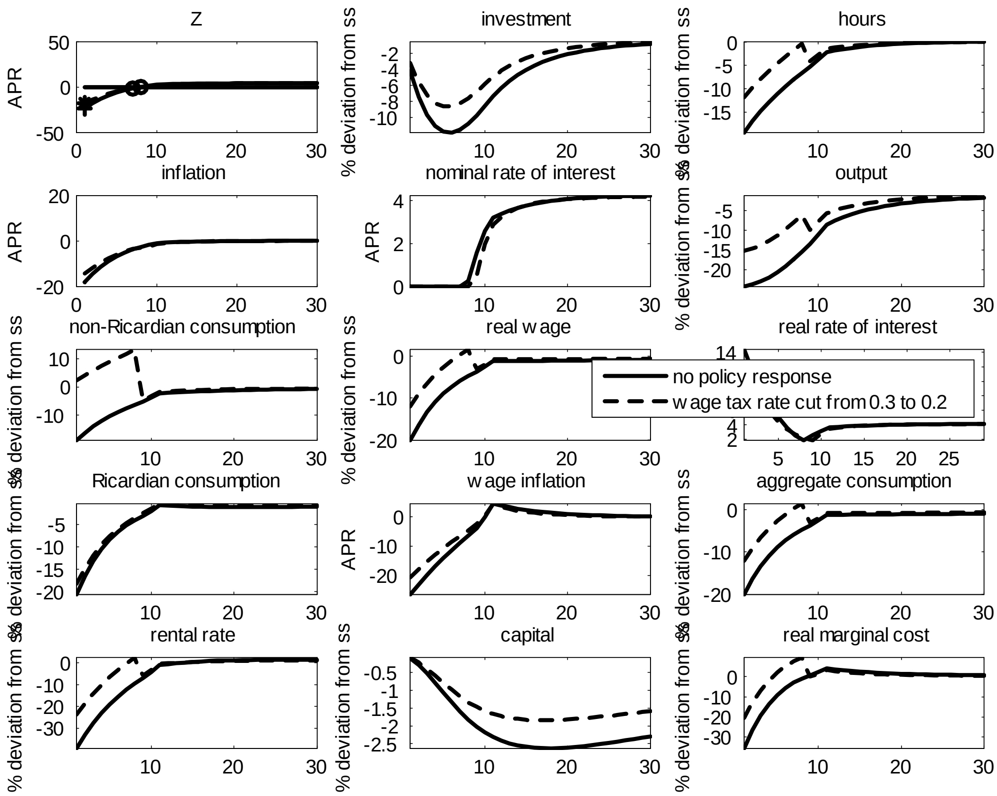

Figure 5: This is called Experiment 5 in the text. The model used here is the same as in Experiment 4 augmented with external habit in consumption, capital utilisation and strategic complementarity in the form of Kimball-demand.