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By

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Investment-specific technology shocks and consumption*

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Abstract

Modern business cycle models systematically underestimate the correlation between consumption and investment. One reason for this failure is that, generally, positive investment-specific technology shocks induce a negative consumption response. The objective of this paper is to investigate whether a positive consumption response to investment-specific technology shocks can be obtained in a modern business cycle model. We find that the answer to this question is yes. With a combination of nominal rigidities and non-separable preferences, the consumption response is positive for very general parameterisations of the model.

JEL classification: E32. *Keywords*: investment-specific technology shocks, consumption, GHH preferences, nominal rigidities, comovement.

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1 Introduction

Investment-specific technology (IST) shocks are shocks to the marginal efficiency of investment. Following Greenwood, Hercowitz and Krusell (2000), these shocks have gained in prominence in the literature as potentially important sources of business cycle fluctuations. For example, Justiniano, Primiceri and Tambalotti, henceforth JPT, (2010) have recently found that IST shocks are the most important drivers of aggregate fluctuations in an estimated dynamic stochastic general equilibrium (DSGE) model of the US economy. In their model, IST shocks account for 50 per cent of fluctuations in output, 83 per cent of those in investment and 59 per cent of the variability of hours worked. As these variables all increase on impact of the shock, this is in keeping with the empirical observation that key real variables co-move at business cycle frequencies. However, consumption fails to co-move with other key macroeconomic variables in the JPT (2010) model in contrast with the characterics of empirically recognisable business cycles. Specifically, a positive IST shock leads to a decline in consumption on impact. Moreover, IST shocks explain only six per cent of consumption volatility according the variance decomposition.

In this paper, we investigate whether it is possible to obtain a positive consumption reaction to IST shocks in a standard DSGE model.[1] This is interesting for two reasons. First, the lack of co-movement of consumption with other key variables in response to IST shocks is not compensated for by other shocks in the model estimated by JPT (2010). In fact, the model underestimates the correlation between consumption and investment, which is positive in the data and negative in the model. In contrast, the JPT (2010) model performs very well in reproducing other cross-correlations. Second, evidence from VAR studies suggests that consumption increases significantly on impact of an IST shock, cf. Peersman and Straub (2007).

We find that a positive consumption response can be obtained in a standard DSGE model with nominal rigidities when preferences are non-separable in con-

[1] Similar objectives are persued in different settings in the contemporaneous work by Eusepi and Preston (2009), Guerrieri, Henderson and Kim (2009), and Khan and Tsoukalas (2009).

sumption and hours. This holds for the general class of non-separable preferences proposed by Jaimovich and Rebelo (2009) that nests as limiting cases the preferences proposed by Greenwood, Hercowitz and Huffmann, henceforth GHH, (1988) and the preferences proposed by King, Plosser and Rebelo, henceforth KPR, (1988). However, the positive effect of consumption is stronger in the GHH (1988) limit, which implies a large degree of complementarity between consumption and hours worked, cf. Monacelli and Perotti (2008).

Nominal rigidities are essential for this result to hold. When prices and wages are flexible, we can show analytically that the impact response of hours and output is zero. This implies that the boom in investment induced by an IST shock has to be exactly off-set by a decline in consumption. Unlike GHH (1988), we find that variable capacity utilisation affects the transmission mechanism for IST shocks only marginally.

The paper is organised as follows. Section 2 presents the model and its calibration. Results are presented and analysed in section 3. In section 4, we dig deeper into the transmission mechanism under various alternative assumptions. In section 5, we compare our results to other papers in the literature. Some concluding remarks are given in section 6.

2 The model

The model is a standard New Keynesian dynamic stochastic general equilibrium model extended with endogenous capital accumulation, variable capital utilisation and investment-adjustment costs. The economy consists of a continuum of firms, a continuum of households, and an inflation-targeting central bank. There is monopolistic competition in goods and labour markets, and perfect competition in capital rental markets.

Using Cobb-Douglas technology, each firm combines rented capital with an aggregate of the differentiated labour services supplied by individual households to produce a differentiated intermediate good. It sets the price of its good according to a Calvo price-setting mechanism and stands ready to satisfy demand at the chosen price. Given this demand, and given wages and rental rates, the firm chooses the relative factor inputs to production to minimise its costs.

Each household consumes a bundle of the intermediate goods produced by individual firms. Each period, it chooses how much to consume of this final good (in addition to its composition) and how much to invest in state-contingent one-period bonds. As in Christiano, Eichenbaum and Evans (2005), it also chooses how much to invest in new capital subject to investment adjustment costs, and it chooses the utilisation rate of its current capital stock subject to utilisation costs. Finally, the household chooses the hourly wage rate for its labour service, and it stands ready to meet demand at the chosen wage.

We consider two specifications of the household felicity function. The first is the non-separable specification proposed by Jaimovich and Rebelo (2009), and the second is the separable specification proposed by Galí (2010).

Each period begins by the realisation of shocks to the economy. We concentrate on IST shocks, i.e., shocks to the extent to which output devoted to investment increases the capital stock available for use in production. We abstract from other shocks that may affect the economy.

2.1 Monopolistic competition

The labour used in production in each firm $i \in [0, 1]$, denoted by $N_t(i)$, is a Dixit-Stiglitz aggregate of the differentiated labour services supplied by households

$$N_t(i) = \left(\int_0^1 N_t(i, j)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} \, dj \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \tag{1}$$

where ε_w is the elasticity of substitution between labour services, and $N_t(i, j)$ represents the hours worked by household $j \in [0, 1]$ in the production process of firm i. Denoting the wage rate demanded by household j by $W_t(j)$, cost minimisation by the firm (for a given level of total labour input) leads to a downward-sloping demand schedule for the labour service offered by this particular households. Aggregating over firms gives the economy-wide demand for the work hours offered by household j

$$N_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} N_t \tag{2}$$

where ε_w represents the elasticity of demand, and $N_t = \int_0^1 N_t(i)\,di$ represents total hours worked in firms across the economy. W_t is the wage index defined as

$$W_t = \left(\int_0^1 W_t(j)^{1-\varepsilon_w}\,dj\right)^{\frac{1}{1-\varepsilon_w}} \tag{3}$$

This wage index has the property that the minimum cost of employing workers for N_t hours is given by $W_t N_t$.

Similarly, the final consumption good that enters household j's utility function is a Dixit-Stiglitz aggregate of the differentiated intermediate goods supplied by firms

$$C_t(j) \equiv \left(\int_0^1 C_t(i,j)^{\frac{\varepsilon_p-1}{\varepsilon_p}}\,di\right)^{\frac{\varepsilon_p}{\varepsilon_p-1}} \tag{4}$$

where ε_p is the elasticity of substitution between product varieties, and $C_t(i,j)$ represents the consumption by household j of the good produced by firm i. Denoting the price demanded by firm i by $P_t(i)$, expenditure minimisation by the household (for a given level of final goods consumption) leads to a downward-sloping demand schedule for the intermediate good produced by this particular firm. Aggregating over households gives the economy-wide consumption demand for good i

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon_p} C_t \tag{5}$$

where ε_p represents the elasticity of demand, and $C_t = \int_0^1 C_t(j)\,dj$ is aggregate consumption. P_t is the price index defined as

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon_p} \, di \right)^{\frac{1}{1-\varepsilon_p}} \tag{6}$$

This price index has the property that the minimum expenditure required to purchase C_t units of the composite good is given by $P_t C_t$.

Assuming that the elasticity of substitution between varieties of goods is the same when purchased for investment and for maintenance of machinery as when consumed, aggregate demand for an intermediate good i is given by

$$Y_t^d(i) \equiv C_t(i) + I_t(i) + M_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon_p} (C_t + I_t + M_t) \tag{7}$$

where $I_t(i)$ represents goods produced by firm i that households devote to capital accumulation, while $M_t(i)$ denotes those devoted to covering capital utilisation costs, which we may think of as maintenance of the existing capital stock. Omission of firm indices indicate corresponding economy-wide variables (in per capita terms).

Aggregate output is defined as

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon_p - 1}{\varepsilon_p}} \, di \right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}} \tag{8}$$

where $Y_t(i)$ is the output of firm i. Market clearing requires that $Y_t^d(i) = Y_t(i)$. The aggregate resource constraint in the economy is therefore

$$Y_t = C_t + I_t + M_t \tag{9}$$

2.2 Households

Each household $j \in [0,1]$ maximises its expected discounted utility given by

$$E_t \sum_{k=0}^{\infty} \beta^k U(C_{t+k}(j), N_{t+k}(j)) \tag{10}$$

where β is the subjective discount factor.

We consider two specifications of the instantaneous utility function. As a baseline, we use the non-separable specification proposed by Jaimovich and Rebelo (2009)

$$U\left(C_t\left(j\right), N_t\left(j\right)\right) = \frac{\left(C_t\left(j\right) - \chi N_t\left(j\right)^{1+\eta} X_t\right)^{1-\sigma} - 1}{1-\sigma} \tag{11}$$

where

$$X_t = C_t^{\vartheta} X_{t-1}^{1-\vartheta}$$

is a preference shifter that depends on current and past aggregate consumption levels. The presence of X_t implies that preferences are not time-separable. These preferences nest as special cases two of the most widely used families of non-separable preferences. When $\vartheta = 1$ we recover the preference specification of King, Plosser and Rebelo (1988), while we obtain the preferences suggested by Greenwood, Hercowitz and Huffman (1988) when $\vartheta = 0$. We refer to these special cases as KPR and GHH preferences, respectively.

To evaluate the importance of non-separability, we also consider the family of separable preferences proposed by Galí (2010):

$$U\left(C_t\left(j\right), N_t\left(j\right)\right) = \Theta_t \log C_t\left(j\right) - \chi \frac{N_t\left(j\right)^{1+\eta}}{1+\eta} \tag{12}$$

where Θ_t is a preference shifter determined by the ratio of aggregate consumption to a measure of its trend level ($\Theta_t = C_t/X_t$). Notice that when $\vartheta = 1$ we recover the standard log-separable preferences, cf. e.g. Smets and Wouters (2007), while we obtain a separable utility function without wealth effects on labour supply when $\vartheta = 0$.

With non-separable preferences, the marginal utilities of consumption and labour are

$$MU_{C,t}^{NON-SEP}(j) = \left(C_t(j) - \chi N_t(j)^{1+\eta} X_t\right)^{-\sigma} \left(1 - \chi\vartheta N_t(j)^{1+\eta} C_t^{-1} X_t\right) \tag{13}$$

and

$$MU_{N,t}^{NON-SEP} = -\left(C_t(j) - \chi N_t(j)^{1+\eta} X_t\right)^{-\sigma} \chi(1+\eta) N_t(j)^{\eta} X_t \tag{14}$$

respectively. With separable preferences, we get

$$MU_{C,t}^{SEP}(j) = \frac{\Theta_t}{C_t(j)} \tag{15}$$

and

$$MU_{N,t}^{SEP}(j) = -\chi N_t(j)^{\eta} \tag{16}$$

The two specifications therefore result in different marginal rates of substitution between consumption and labour effort. With non-separable, we get

$$MRS_t^{NON-SEP} = -\frac{MU_{N,t}^{NON-SEP}(j)}{MU_{C,t}^{NON-SEP}(j)} = \frac{\chi(1+\eta) N_t(j)^{\eta} X_t}{1 - \chi\vartheta N_t(j)^{1+\eta} C_t^{-1} X_t} \tag{17}$$

while the marginal rate of substitution with separable preferences is

$$MRS_t^{GHH} = -\frac{MU_{N,t}^{SEP}(j)}{MU_{C,t}^{SEP}(j)} = \frac{\chi N_t(j)^{\eta} C_t(j)}{\Theta_t} \tag{18}$$

Households own the capital stock and let this capital to firms in a perfectly competitive rental market at the real rental rate R_t^K. Each household chooses the rate at which its capital is utilised, $U_t(j)$, which transforms the accumulated capital stock, $\bar{K}_{t-1}(j)$, into effective capital in period t, $K_t(j)$, according to

$$K_t(j) = U_t \bar{K}_t(j) \tag{19}$$

Following Christiano, Eichenbaum and Evans (2005), the cost of capital utilisation is given by the increasing and convex function $a(.)$ so that $M_t(j) = a(U_t(j))\bar{K}_t(j)$. Steady-state utilisation is normalised to $U = 1$, and we assume $a(1) = 0$ and $a'(.), a''(.) > 0$.

The capital accumulation equation is given by

$$\bar{K}_{t+1}(j) = (1-\delta)\bar{K}_t(j) + Z_t\left(1 - S\left(\frac{I_t(j)}{I_{t-1}(j)}\right)\right) I_t(j) \tag{20}$$

where $I_t(j)$ is the amount of the final good acquired by the household for investment purposes, δ represents the depreciation rate of capital, and $S(.)$ is a function representing investment-adjustment costs. We assume that $S(1) = S'(1) = 0$ and $S''(1) > 0$.

Z_t is the IST shock, which affects the extent to which resources allocated to investment (net of investment-adjustment costs) increase the capital stock available for use in production next period. It is therefore a shock to the marginal efficiency of investment. The shock evolves according to the autoregressive process

$$\log Z_t = \rho_z \log Z_{t-1} + \epsilon_{z,t} \tag{21}$$

where $0 < \rho_z < 1$, and $\epsilon_{z,t}$ is white noise.

Household maximisation is subject to a sequence of budget constraints taking the following form

$$\begin{aligned} & P_t\left[C_t(j) + I_t(j) + M_t(j)\right] + E_t\left(\Lambda_{t,t+1}B_{t+1}(j)\right) \\ \leq\ & B_t(j) + W_t(j)N_t(j) + T_t(j) + P_tR_t^K K_t(j) - F_t(j) \end{aligned} \tag{22}$$

The left-hand side gives the allocation of resources to consumption, investment, capital adjustment costs, and to a portfolio of bonds, $E_t(\Lambda_{t,t+1}B_{t+1}(j))$, where $\Lambda_{t,t+1}$ is the stochastic discount factor and $B_{t+1}(j)$ represents contingent claims.[2]

[2]The stochastic discount factor $\Lambda_{t,t+1}$ is defined as the period-t price of a claim to one unit of currency in a particular state in period $t+1$, divided by the period-t probability of that state

Hence, the risk-free (gross) nominal interest rate is defined by $R_t = (E_t \Lambda_{t,t+1})^{-1}$. The right-hand side gives available resources as the sum of bond holdings, labour income net of a wage adjustment cost, $F_t(j)$, dividends from firms, denoted by T_t, and rental income from capital.

First-order conditions with respect to consumption and bond holdings gives rise to an Euler equation summarising the intertemporal consumption allocation choice of households. It takes the standard form

$$1 = R_t E_t \Lambda_{t,t+1}. \tag{23}$$

where the stochastic discount factor is given as

$$\Lambda_{t,t+1} = \beta \frac{MU^l_{C,t+1}}{MU^l_{C,t}} \frac{P_t}{P_{t+1}}$$

$l \in \{NON - SEP, SEP\}$ is an index for the type of preferences assumed so that $MU^l_{C,t}$ is the marginal utility of consumption as specified above. The assumption of complete markets allows us to drop household indices in this expression (and in many of those that follow). First-order conditions imply that risk-sharing is complete in consumption and investment under the complete market assumption as long as initial endowments are identical. That is, $C_t(j) = C_t$, $I_t(j) = I_t$, $\bar{K}_t(j) = \bar{K}_t$ and $U_t(j) = U_t$ for all $j \in [0,1]$.

First-order conditions with respect to investment and capital equates marginal cost and benefits of additional investment and capital

$$\begin{aligned} 1 &= Q_t Z_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] \\ &\quad + E_t \left[\Lambda_{t,t+1} \frac{P_{t+1}}{P_t} Q_{t+1} Z_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right] \end{aligned} \tag{24}$$

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occuring.

$$Q_t = \beta E_t \left\{ \Lambda_{t,t+1} \frac{P_{t+1}}{P_t} \left[R^K_{t+1} U_{t+1} - \frac{M_{t+1}}{\bar{K}_{t+1}} + Q_{t+1} \left(1 - \delta_t\right) \right] \right\} \tag{25}$$

The variable Q_t, representing Tobin's q, is equal to the ratio of the Lagrange multipliers attached to the capital accumulation equation and the budget constraint, respectively.

Similarly, the first-order condition with respect to capital utilisation equates the marginal benefit of raising capital utilisation with the marginal cost of doing so

$$R^K_t = a' \left(U_t\right) \tag{26}$$

Wage adjustments are assumed to be costly. In particular, it is assumed that the wage adjustment cost is a quadratic function of the increase in the wage demanded by the worker as modelled in Rotemberg (1982) for prices demanded by firms. For simplicity, the adjustment cost is proportional to the aggregate wage bill in the economy (this parallels the specification of price adjustment costs in Ireland, 2003). Though the wage bargaining process is not explicitly modelled, one way of thinking of this cost is that workers have to negotiate wages each period and that this activity is costly; the larger the increase in wages obtained, the more effort workers would have needed to put into the negotiation process. The nominal wage adjustment cost is given by

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

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

The first-order condition is given by

$$\begin{aligned} 0 \quad = \quad & \frac{W_t}{P_t} \left[\left(1 - \varepsilon_w\right) - \phi_w \left(\Pi^w_t - 1\right) \Pi^w_t \right] + \varepsilon_w MRS^l_t \\ & + \beta E_t \left[\frac{MU^l_{C,t+1}}{MU^l_{C,t}} \phi_w \left(\Pi^w_{t+1} - 1\right) \Pi^w_{t+1} \frac{W_{t+1}}{P_{t+1}} \frac{N_{t+1}}{N_t} \right] \end{aligned} \tag{27}$$

where $\Pi^w_t = W_t / W_{t-1}$ after imposing symmetry so that $W_t \left(j\right) = W_t$ and $N_t \left(j\right) = N_t$.

Again, $l \in \{NON - SEP, SEP\}$ denotes the class of preferences.

2.3 Firms

Each firm $i \in [0,1]$ produces a differentiated good, $Y_t(i)$, according to

$$Y_t(i) = K_t(i)^{\alpha} N_t(i)^{1-\alpha} \tag{28}$$

where $K_t(i)$ denotes the period-t capital stock rented by firm i, and $N_t(i)$ is the number of hours worked in the production process of firm i.

Firm i's marginal cost can be found as the Lagrange multiplier from the firm's cost minimisation problem

$$MC_t(i) = \frac{W_t/P_t}{(1-\alpha)\left(K_t(i)/N_t(i)\right)^{\alpha}} = \frac{R_t^K}{\alpha\left(N_t(i)/K_t(i)\right)^{1-\alpha}} \tag{29}$$

where R_t^K denotes the real rental rate of capital. Conditional factor demand schedules imply that firm i will choose factor inputs such that

$$\frac{K_t(i)}{N_t(i)} = \frac{\alpha}{1-\alpha}\frac{W_t/P_t}{R_t^K} \tag{30}$$

This equation implies that, on the margin, the cost of increasing capital in production equals the cost of increasing labour. 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 (of increasing output) are equalised across firms regardless of any heterogeneity in output induced by differences in prices. Hence, $MC_t(i) = MC_t \; \forall i$ where

$$MC_t = \frac{1}{1-\alpha}\left(\frac{\alpha}{1-\alpha}\right)^{-a}\left(\frac{W_t}{P_t}\right)^{1-\alpha}\left(R_t^K\right)^{\alpha} \tag{31}$$

follows from combining (29) and (30).

Consequently, the marginal product of labour

$$MPL_t(i) = (1-\alpha) Y_t(i) / N_t(i) = \frac{W_t/P_t}{MC_t(i)} \tag{32}$$

is also equalised across firms so that $MPL_t(i) = MPL_t \; \forall i$.

Firms follow a Calve price-setting mechanism when setting prices. Each period, a measure $(1-\theta_p)$ of randomly selected firms get to post new prices, while remaining firms must keep their prices constant. A firm allowed to choose a new price at time t sets $P_t(i) = P_t^*$ to maximise the value of the firm to its owners, the households. At time t, this value is given by

$$\sum_{k=0}^{\infty} E_t \left\{ \Lambda_{t,t+k} \left[P_{t+k}(i) Y_{t+k}(i) - \Psi\left(Y_{t+k}(i)\right) \right] \right\} \tag{33}$$

where $\Lambda_{t,t+k}$ is the stochastic discount factor, and $\Psi(.)$ is the cost function (i.e. the value function from the cost minimisation problem described above). Optimisation is subject to the demand for the firm's product, (7), its production technology, (28), and the restriction from the Calvo mechanism that

$$P_{t+k+1}(i) = \begin{cases} P_{t+k+1}^* & \text{w.p.} \left(1-\theta_p\right) \\ P_{t+k}(i) & \text{w.p.} \theta_p \end{cases} \tag{34}$$

The first-order condition is given by

$$\sum_{k=0}^{\infty} \theta_p^k E_t \left\{ \Lambda_{t,t+1} Y_{t+k}(i) \left[P_t^* - \mu P_{t+k} MC_{t+k} \right] \right\} = 0 \tag{35}$$

where $\mu_p \equiv \varepsilon_p (\varepsilon_p - 1)^{-1}$ is the desired mark-up of price over nominal marginal cost. This condition reflects the forward-looking nature of price-setting; firms take not only current but also future expected marginal costs into account when setting prices.

2.4 Monetary policy

We assume that the central bank reacts to inflation $\Pi_t^p = (P_t - P_{t-1})/P_{t-1}$ and to output growth according to a simple Taylor rule with interest rate smoothing

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left(\frac{\Pi_t^p}{\Pi^p}\right)^{\phi_\pi(1-\rho_r)} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_y(1-\rho_r)} \tag{36}$$

where the omission of time subscripts indicate steady-state values, $0 < \rho_r < 1$ governs monetary policy inertia, ϕ_π and ϕ_y measure the response to inflation and to output growth.

2.5 Calibration

We calibrate the model's parameter values and solve it numerically after log-linearising the equilibrium conditions. The steady state around which we log-linearise is characterised in appendix A, and the log-linear relations are summarised in appendix B.

We consider the length of a period to be one quarter, and we let $\beta = 0.99$ implying that the annual interest rate is about 4 per cent in steady state. We set the depreciation rate to $\delta = 0.025$ and the capital share to $\alpha = 0.33$. We assume a moderate amount of complementarity between consumption and labour by setting $\sigma = 2$. Kilponen, Wilmunen and Vähämaa (2010) provide evidence in favour of a larger degree of complementarity that would reinforce our main result. In our baseline case we consider the GHH limit in the Jaimovich and Rebelo (2009) family of preferences. Therefore, we set ϑ equal to 0. However, we compare our baseline case with several alternatives. Desired mark-ups in both labour and goods markets are assumed to be 20 per cent, which we achieve by setting $\varepsilon_p = \varepsilon_w = 6$. We use χ to pin down hours in steady state to $N = 1/3$ of available time. These are values in line with those commonly found in the New Keynesian literature, see, e.g., Christiano, Eichenbaum and Evans (2005), Galí (2008), Golosov and Lucas (2007) and Smets and Wouters (2007).

We set the inverse of the second derivative of the investment adjustment cost function to $\lambda_s = 0.37$, smaller than the 0.4 estimated by Christiano, Eichenbaum and Evans (2005), but larger than the 0.34 estimated by Justiniano, Primiceri and Tambalotti (2010) and the 0.17 estimated by Smets and Wouters (2007) In the log-linear model, this is the only characteristic of the investment adjustment function with implications for the model's propagation mechanism. By reducing the convexity of the adjustment cost function, an increase in λ_s leads to a smaller investment adjustment cost for a given change in investment. Hence, the sensitivity of households' investment decisions to changes in the current value of installed capital (Tobin's q) will increase as λ_s increases.

Our benchmark IST shock is moderately persistent with $\rho_z = 0.7$. This is in keeping with values estimated by JPT (2010) and Smets and Wouters (2007).

We consider the implications of both fixed and variable capacity utilisation. When allowing for variable capacity utilisation, we set the elasticity of marginal utilisation costs to $\lambda_a = 1.17$ (fixed utilisation is achieved by letting $\lambda_a \to \infty$), the value estimated by Smets and Wouters (2007). In the log-linear model, this is the only characteristic of the capital utilisation cost function with implications for the model's propagation mechanism. An increase in λ_a increases the effect on the marginal capital utilisation costs from an increase in utilisation. Hence, utilisation responds less to a given increase in the rental rate. Effectively, more of the increase in rental income brought about by an increase in capital utilisation will be off-set by maintenance costs as λ_a increases.

We consider both the case with flexible wages and prices, i.e. $\phi_w = \theta_p = 0$, and the case with nominal wage and price rigidity. When allowing for sticky prices and wages, we set $\theta_p = 0.7$ (corresponding to slightly more than three quarters of average price duration) and $\phi_w = 407.7$ (corresponding to four quarters of average wage duration under the alternative Calvo wage setting scheme). Our choice strikes a balance between the microdata evidence provided by Bils and Klenow (2004) and Nakamura and Steinsson (2008) for prices, and the slightly larger values usually considered for wages.

In calibrating the monetary policy rule, we use estimates from Galí and Rabanal (2005) and we set $\rho_r = 0.69$, $\phi_\pi = 1.35$ and $\phi_y = 0.26$.

Finally, our benchmark calibration of the inverse of the labour supply elasticity sets $\eta = 1$ corresponding to a labour elasticity of 1. This is a common value in the business cycle literature. It makes labour relatively elastic to take fluctuations along the extensive margin (employment) that are not explicitly modelled into account.

3 Results

Figur 1 shows responses to a positive IST shock for three version of the model presented in the previous section. The solid lines represent our baseline model with GHH preferences, i.e., utility function (11) with $\vartheta = 0$. The dashed lines refer to the same model with standard log-separable preferences, i.e., utility function (12) with $\vartheta = 1$. Finally, the dotted lines represent the model with log-separable preferences, but with fixed capacity utilisation and flexible prices and wages. Essentially, this reduces the model to a standard real business cycle (RBC) model.

The figure illustrates the main result of this paper: Our baseline model with non-separable preferences delivers a positive and hump-shaped response of consumption to an IST shock. In fact, the four key macroeconomic variables output, consumption, investment and hours all co-move as in an empirically recognisable business cycle. Moreover, the IST shock resembles a demand shock in that both prices and quantities increase, while the response of real wages is limited.

The key ingredient to obtain this positive consumption response is the preference specification. When we use the standard log-separable preferences (dashed lines), consumption declines after an IST shock as in JPT (2010).[3] Moreover, when we

[3] This is not surprising given that our model is very similar to the one in their paper except for the alternative preference specifications. Their model also features habit persistence in consumption and indexation in prices and wages. These ingredients do not play an important role in the transmission of IST shocks, however.

simulate the RBC version of our model with fixed utilisation and flexible prices and wages (dotted line), the negative response of consumption is even stronger and the response of output is muted. Thus, nominal rigidities and variable capacity utilisation are instrumental in generating the expansionary effects on output from IST shocks found by JPT (2010), but the standard log-separable preference specification works to prevent the co-movement of consumption with other key variables that we see in a typical business cycle. In contrast, our model with non-separable preferences, nominal rigidities and variable capacity utilisation generates both a strong expansion in the economy and co-movement of key aggregate variables.

To provide the intuition for this, we follow JPT (2010) by considering the labour market equilibrium condition. With sticky prices and wages, mark-ups in goods and labour markets will generally deviate from their desired levels. We therefore implicitly define the economy's average mark-up in goods and labour markets, respectively, as

$$\mu_{p,t} \equiv \frac{MPL_t}{W_t/P_t} \tag{37}$$

and

$$\mu_{w,t} \equiv \frac{W_t/P_t}{MRS_t^l} \tag{38}$$

where MRS_t^l represents the economy's average marginal rate of substitution for $l \in \{NON-SEP, SEP\}$. We may think of (37) as a labour demand and (38) as a labour supply schedule. Hence, equating inverse demands gives the labour market equilibrium condition

$$MPL_t = \mu_t MRS_t^l \tag{39}$$

where the variable $\mu_t \equiv \mu_{p,t}\mu_{w,t}$ represents the time-varying wedge driven between the marginal rate of substitution and the marginal product of labour as a consequence of monopolistic competition and nominal rigidities in both goods and labour markets. Notice that changes in capital utilisation affects the labour demand schedule through its effect on effective capital. An increase in the rate of capital utilisation increases the marginal product of labour for given hours and therefore works to shift the labour demand curve upwards in $(N, W/P)$ space.

We first consider the case in which prices and wages are flexible, preferences are separable, and capital utilisation is fixed (the dotted line in figure 3). With flexible wages and prices, mark-ups in goods and labour markets are constant and equal to their desired levels, cf. (27) and (35). The marginal product of labour is a negative function of aggregate hours worked, and as effective capital is predetermined when utilisation is fixed, only hours can affect the marginal product of labour on impact of a shock. With log-separable preferences, the average marginal rate of substitution is a positive function of consumption and of aggregate hours. Hence in this case, (39) becomes

$$MPL_t\left(\underset{-}{N_t}\right) = \mu MRS_t\left(\underset{+}{C_t}, \underset{+}{N_t}\right) \tag{40}$$

where $\mu = \mu_p \mu_w$.

As discussed by Barro and King (1984), GHH (1988) and more recently by JPT (2010), the IST shock will raise hours worked (as long as consumption and leisure are normal goods). The only way to satisfy the equilibrium, and therefore to have a decline in the marginal rate of substitution is through a decline in consumption, that is a downward shift in the labour supply curve. This works through an intertemporal substitution effect on hours worked. An investment-specific technology shock (increasing the marginal efficiency of capital) increases the rate of return on investment. As a consequence, intertemporal substitution makes households shift demand away from consumption towards investment. The decline in consumption shifts the labour supply curve, i.e. the right-hand side of (40), down. As a result, while consumption declines, hours increase to produce more investment goods. This reasoning is confirmed in figure 3 (dotted line). Notice that the negative response of consumption in this version of the model does not depend on the chosen calibration.

When we introduce sticky wages, sticky prices and variable capacity utilisation, we obtain a model that is very similar to the one proposed in JPT (2010). Variable capacity utilisation allows shifts in labour demand. Moreover, when wages and prices are sticky, mark-ups in both goods and labour markets will generally deviate from their desired levels and will vary over time. And changes in the wedge driven between the marginal rate of substitution and the marginal product of labour as a consequence of monopolistic competition may amplify the effects of that shift in labour demand on the equilibrium outcome. In this case, we may write (39) as

$$\mu_t^{-1} MPL_t \left(\underset{-}{N_t}, \underset{+}{U_t} \right) = MRS_t \left(\underset{+}{C_t}, \underset{+}{N_t} \right) \tag{41}$$

Any upward shift in the labour demand curve as a consequence of an increase in capital utilisation will be accompanied by a shift in mark-ups, leading to a larger effect on hours worked in equilibrium.

Consequently, variable capacity utilisation and nominal rigidities constitute a promising combination for the purpose of generating an increase in consumption along with hours and output on impact of an investment-specific technology shock. However, it turns out that, as in JPT (2010), variable capacity utilisation and nominal rigidities are not sufficient to overturn the intertemporal substitution effect on consumption (dashed line in figure 3).

With non-separable preferences, instead, an increase in hours worked has a positive effect on the marginal utility of consumption. The reason for this is that consumption and hours are complements in the utility function. Hence, unless monetary policy is very aggressive in increasing interest rates, the complementarity will work to drive up consumption with the increase in hours worked through the Euler equation. Indeed, as shown in figure 3 (solid lines), the increase in consumption is comfortable positive with non-separable preferences. As shown by Monacelli and Perotti (2008), the degree of complementarity is larger as we approach the GHH limit in the family of non-separable preferences in (11). With GHH preferences, the marginal rate of substitution is independent of consumption, while the presence of labour demand shifters favours a large expansionary effect on hours worked.

4 Inspecting the mechanism

In the previous section we have shown that our baseline model with non-separable preferences, nominal rigidities and variable capacity utilisation generates both a strong expansion in the economy and co-movement of key aggregate variables including consumption. In this section, we inspect the mechanism behind this result further by addressing two issues. First, we investigate whether capacity utilisation and nominal rigidities are essential to obtain a positive consumption response. Second, we want to clarify why Jaimovich-Rebelo preferences, in particular in the GHH limit, are so powerful in generating co-movement of consumption.

4.1 Are variable capacity utilisation and nominal rigidities essential?

In figure 2 we simulate the baseline version of our model with GHH preferences and a version of the same model with fixed capital utilisation. The figure shows that the propagation through variable capacity utilisation is very limited. In fact, the consumption response is very close to the one in the model with fixed capacity utilisation. Therefore, our model does not rely on variable capacity utilisation to achieve a positive consumption response.

Are nominal rigidities essential then? In figure 2 (dotted line) we also simulate our baseline model with flexible prices and wages (keeping variable capacity utilisation). In this case, the positive consumption response is lost. Thus, a combination of non-separable preferences and variable capacity utilisation is not able to generate a positive consumption response.

This result can be shown analytically by combining first-order conditions. With flexible prices and wages, first-order conditions imply that

$$\left[(1+\lambda_a)\left(\frac{\alpha+\eta}{\alpha}\right)-(1+\eta)\right]n_t=\lambda_a\bar{k}_t \tag{42}$$

As $\bar{k}_t$ is a predetermined variable that cannot respond on the impact of the shock, it follows that hours cannot react on impact of the shock either. And if hours worked do not react, real wages, the rental rate of capital and the utilisation do not react, which means that output does not move. But then, equilibrium in the good market will be achieved through intertemporal substitution of consumption and investment only, that is through a decline in consumption that exactly offsets the increase in investment brought about by the IST shock. Only as the new investments increase the capital stock will the labour demand schedule gradually shift out, increasing hours, output and the real wage, and allowing consumption to recover (see dotted line in figure 2). In fact, GHH preferences lead to a larger decline in consumption then would standard log-separable preferences in this case. With log-separable preferences, part of the intertemporal substitution work through a reduction in leisure rather than in the consumption of goods. By (42), this is not the case with GHH preferences.

In sum, for our main result to hold, a combination of non-separable preferences and nominal rigidities is needed. Capital utilisation, in contrast, plays a limited role in the transmission mechanism. Therefore, in this context, the effect of nominal rigidities through labour demand is more powerful than the one of variable capacity utilisation. Notice that this result does not depend on the calibration. In particular, it will hold for any degree of persistence of the shock or any value for the labour supply elasticity.

4.2 Complementarity of the absence of wealth effects on labour supply?

The shift from the standard log-separable to the GHH utility function has two implications for household preferences. This first is that GHH preferences eliminate the wealth effect on labour supply, i.e., the marginal rate of substitution does not depend on consumption. The second is that GHH preferences introduces a complementarity between consumption and hours worked as hours worked enter into the expression for the marginal utility of consumption. To disentangle the importance each of these changes, we simulate our model under different preference specifications.

The first alternative to GHH preferences that we consider is the opposing KPR limit of the Jaimovich-Rebelo utility function. That is, we simulate the model setting $\vartheta = 1$ in the family of non-separable preferences in (11). With this specification, there is a complementarity between consumption and hours worked, but the wealth effect on labour supply is positive. The second alternative, in contrast, eliminates the wealth effect on labour supply without introducing a complementarity between consumption and leisure. We achieve this by setting $\vartheta = 0$ in the Galí (2010) specification of utility in (12).

The comparison of these three cases is particularly instructive, in our opinion, because it allows us to disentangle the role played by complementarity and by a zero wealth effect on labour supply. With GHH preferences, the two features co-exist, with KPR preferences we have complementarity but a positive wealth effect on labour supply, whereas the Galí (2010) preferences with $\vartheta = 0$ give a zero wealth effect on labour supply but no complementarity between consumption and hours.

We plot the results of this comparison in figure 3. The solid lines refer to the baseline version of the model with GHH preferences, the dashed lines represent the model with KPR preferences, and the dotted line the model with Galí preferences.

Considering the responses with KPR preferences first, we see that co-movement across the key real variables is not dependant on a zero wealth effect on labour supply. The response of consumption is weaker, but remains positive on impact and in all periods following the shock. For values of ϑ lower than 1, the impact response of consumption will be larger and it will approach the GHH limit for values of ϑ close to 0. Hence, while a zero wealth effect contributes to the expansion in consumption, a positive consumption response is not incompatible with a positive wealth effect on labour supply.

In constrast, when we consider Galí preferences (dotted lines in figure 3), the positive response of consumption is lost. As the marginal utility of consumption is constant under Galì preferences with $\vartheta = 1$, the real interest rate is constant. This favours investment, shifting demand away from consumption even more than in the log-separable case (shown in figure 1). The decline in consumption is so large that it is accompanied by a decline in hours. This implies that the absence of a wealth effect on labour supply is not sufficient to guarantee a positive response for consumption.

In sum, our results suggest that GHH preferences are successful at generating a positive consumption response first and foremost because they imply a large degree of complementarity between consumption and labour rather than because they eliminate the wealth effect on labour supply.

5 Our results in perspective

In this section, we briefly relate our results to the existing literature. The comovement problem of consumption following IST shocks was first addressed by GHH (1988). They emphasise a combination of non-separable preferences and variable capacity utilisation as a way of obtaining procyclical consumption responses in a RBC model with flexible wages and prices. This is in contrast with our conclusion that variable capacity utilisation plays a minor role in the transmission of IST shocks.

A first difference that distinguishes our paper from theirs is the way we model variable utilisation costs. We follow Christiano, Eichenbaum and Evans (2005) by using a 'maintenance cost' specification of utilisation costs. The idea behind this specification is that an intensified utilisation of capital increases the cost of maintaining the capital stock. Instead, GHH (1988) make use of a 'user cost' specification where an increase in utilisation increases the rate of depreciation of the capital stock. With this alternative specification, the tight restriction on equilibrium dynamics in (42) no longer holds, and hours worked are free to move on impact of the shock also in a model with flexible wages and prices. However, when we simulate the RBC version of our model (with flexible prices and wages) and a user cost specification of capacity utilisation costs, hours increase only marginally. Only when both the utilisation and the labour margin are very elastic ($\eta = 0.4$ and $\lambda_a = 0.15$) is it possible to reproduce a positive response of consumption on impact of the shock, cf. figure 4, but the impact response is very small.[4] Hence, while nominal rigidities and non-separable preferences deliver a positive response of consumption under very general conditions, the combination of GHH preferences and variable capacity utilisation is sensitive to the choice of specification and parameter values when nominal rigidities are absent. In particular, it relies on the user cost specification of variable capacity utilisation costs and highly elastic labour and utilisation margins.

When we simulate our baseline model with non-separable preferences and nominal rigidities with the user cost specification of capacity utilisation, the consumption response remains positive, but it is less strong than with the benchmark maintenance cost specification, cf. figure 5. On first inspection, this result appears to be in contrast with the findings of Khan and Tsoukalas (2009). In an estimated model similar to ours, they find a stronger positive response of consumption with the user cost specification (favoured by a marginal likelihood comparison) than with the maintenance cost specification. However, they estimate a larger degree of nominal rigidity and a larger degree of complementarity in the model with the user cost specification than in the one with maintenance costs of utilisation. Our analysis suggests that these differences in estimated parameter values for the two specifications is driving the difference in the consumption response rather than the utilisation cost specifications themselves. For a given set of parameter values, we find that the user cost specification of GHH (1988) delivers a less expansionary effect as shown in figure 5.

Finally, we note that the combination of nominal rigidity and non-separable preferences can potentially deliver co-movement across real variables in response

[4] GHH (1988) assess the co-movement of consumption by its correlation with output. They do not report impulse response functions. We are able to reproduce the correlations of output with consumption and other key variables that they report by adjusting our calibration to match their parameter values. We also find that the impact response of consumption is negative in this case.

to several shocks other than IST shocks. Indeed, Bilbiie (2010) and Monacelli and Perotti (2009) establish this for fiscal shocks as non-separable preferences allow them to obtain a positive consumption response on impact of an increase in government spending. The same mix of features may also be useful in delivering co-movement in response to preference shocks. Peersman and Straub (2007) show that models with log-separable preferences generate negative co-movement between consumption and investment in response to preference shocks, whereas the co-movement is positive in the data (at least according to their VAR identified with sign restrictions). This suggests that a standard New Keynesian DSGE model extended with non-separable preferences holds the potential to deliver co-movement conditional on several shocks. In the RBC tradition, the neutral technology shock plays an important role exactly because of its ability to generate co-movement of key macroeconomic variables. In our New Keynesian DSGE model, while many shocks could potentially deliver co-movement, the neutral technology shock would fail by generating countercyclical responses in hours worked, cf. see Galí and Rabanal (2005).

6 Concluding remarks

We have developed a DSGE model with monopolistic competition, endogenous capital accumulation, variable capacity utilisation, investment-adjustment costs, and most importantly non-separable preferences and nominal rigidities. We have shown that the presence of these last two ingredients allows for a positive response of consumption on the impact of an IST shock under very general conditions. IST shocks are therefore potentially important drivers of business cycles in New Keynesian models as the co-movement of key macroeconomic variables including consumption is a common feature of empirically recognisable business cycles.

A The steady state

Steady-state variables are indicated by omission of time subscripts. In steady state we have $U = (P^*/P) = 1$ and $\Pi^p = \Pi^W = 0$ where Π^W represents steady-state wage inflation. Hence from (19) $\bar{K} = K$. From (20) we get $I = \delta K$ and from (23) $R = \beta^{-1}$. From (24) we get $Q = 1$ and so from (25) $R^K = \left(\beta^{-1} - 1 + \delta\right)$. (26) now gives a restriction on $a'(1) = R^K$. (35) implies $MC = \mu^{-1}$.

Combining (28) and (29) then gives the restriction

$$\gamma_k \equiv \frac{K}{Y} = \frac{\alpha MC}{R^K} \tag{43}$$

so that

$$\gamma_i \equiv \frac{I}{Y} = \frac{\delta\alpha}{\mu\left(\beta^{-1} - 1 + \delta\right)} \tag{44}$$

Then, from (9) we get

$$\gamma_c \equiv \frac{C}{Y} = 1 - \gamma_i \tag{45}$$

Combining (28) and (20) gives

$$Y = N\left(\gamma_i \delta^{-1}\right)^{\frac{\alpha}{1-\alpha}} \tag{46}$$

and consequently

$$C = \gamma_c Y \tag{47}$$

while (30) now gives

$$\frac{W}{P} = (1 - \alpha)\, MC \frac{Y}{N} \tag{48}$$

Taking N as given, a restriction on χ follows (or, alternatively, given χ we can find N) from (27). With non-separable preferences, this restriction is

$$\chi^{NON-SEP} = \frac{1}{\vartheta N^{1+\eta} + (1+\eta)\, C\mu_w N^{\eta}\,(P/W)} \tag{49}$$

and with separable preferences is

$$\chi^{SEP} = \frac{W/P}{\mu_w C N^{\eta}} \tag{50}$$

This completes the solution of the model in steady state.

B Log-linearisation

We log-linearise the equilibrium dynamics outlined in section 2 around the steady state described in appendix A. Lower case letters denote the log-deviation of a variable from its steady state value.

The relation between the stock of capital and effective capital, (19) becomes

$$k_t = u_t + \bar{k}_t \tag{51}$$

while the capital accumulation equation (20) in log-linear form is given by

$$\bar{k}_{t+1} = (1-\delta)\,\bar{k}_t + \delta\,(i_t + z_t) \tag{52}$$

The consumption Euler equation (23) takes the form

$$\lambda_t^l = E_t \lambda_{t+1}^l + r_t - E_t \pi_{t+1}^p$$

where λ_t^l represents marginal utility of consumption (in log-deviation from the steady state) that under non-separable preferences is equal to

$$\lambda_t^{NON-SEP} = d_2 n_t + d_3 c_t + d_4 x_t \tag{53}$$

where the law of motion for x_t is given by

$$x_t = \vartheta c_t + (1-\vartheta)\,x_{t-1}$$

and $d_1 = \chi\vartheta N^{1+\eta}, d_2 = \left(\frac{-d_1(1+\eta)}{1-d_1}\right) + \frac{\sigma\chi(1+\eta)N^{1+\eta}}{1-\chi N^{1+\eta}}, d_3 = \left(\frac{d_1}{1-d_1}\right) - \frac{\sigma}{1-\chi N^{1+\eta}}, d_4 = \left(\frac{d_1}{1-d_1}\right) + \frac{\sigma\chi(1+\eta)N^{1+\eta}}{1-\chi N^{1+\eta}}$.

The marginal utility of consumption under separable preferences becomes

$$\lambda_t^{SEP} = -x_t \tag{54}$$

The linearised first-order conditions with respect to investment and capital read

$$i_t = \frac{1}{1+\beta}\left(\beta E_t i_{t+1} + i_{t-1} + \lambda_s\left(q_t + z_t\right)\right) \tag{55}$$

$$q_t = -\left(r_t - E_t\pi_{t+1}\right) + \left(1 - \beta\left(1-\delta\right)\right)E_t r_{t+1}^k + \beta\left(1-\delta\right)E_t q_{t+1} \tag{56}$$

where the value of $\lambda_s^{-1} \equiv S''(1) > 0$ governs investment-adjustment costs.

The first-order condition with respect to capital utilisation (26) becomes

$$r_t^k = \lambda_a u_t \tag{57}$$

in its log-linear form where

$$\lambda_a \equiv \frac{a''(U)\,U}{a'(U)} = \frac{a''(1)}{a'(1)} \tag{58}$$

is the elasticity of the marginal costs of capital utilisation.

By combining (27) with the law of motion of the wage index and the labour demand schedule, a standard New Keynesian Phillips curve for wage inflation, π_t^W, is derived as

$$\pi_t^w = \beta E_t\pi_{t+1}^w + \kappa_w\left(mrs_t^l - \left(w_t - p_t\right)\right) \tag{59}$$

for $l \in \{STD, GHH\}$ where $mrs_t^{NON-SEP} = \left(\frac{1+d_1}{1-d_1}\right)x_t + \left(\eta + \frac{d_1(1+\eta)}{1-d_1}\right)n_t - \frac{d_1}{1-d_1}c_t$ is the economy's average marginal rate of substitution under non-separable preferences, and $mrs_t^{SEP} = x_t + \eta n_t$ is the same average under separable preferences. The slope is given by

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

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

$$y_t = \alpha k_t + (1 - \alpha) n_t \tag{60}$$

By combining (35) with the law of motion of the price index, the standard New Keynesian Phillips curve is derived

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \kappa_p mc_t \tag{61}$$

where $\kappa_p = (1 - \beta\theta_p)(1 - \theta_p)\theta_p^{-1}$ and

$$mc_t = (1 - \alpha)(w_t - p_t) + \alpha r_t^k \tag{62}$$

The factor input relation (30) becomes

$$r_t^k = (w_t - p_t) + n_t - k_t \tag{63}$$

The aggregate resource constraint (9) in log-linear from is given as

$$y_t = \gamma_c c_t + \gamma_i i_t + \gamma_k \left(\beta^{-1} - 1 + \delta\right) u_t \tag{64}$$

The monetary policy rule, (36), is

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)\phi_\pi \pi_t^p \tag{65}$$

while the exogenous driving force is specified as

$$z_t = \rho_z z_{t-1} + \epsilon_{z,t} \tag{66}$$

where $\epsilon_{z,t} \overset{iid}{\sim} \left(0, \sigma_{\psi}^2\right)$.

Finally, the model in log-linear form is closed by adding the identity

$$\pi_t^w - \pi_t^p = (w_t - p_t) - (w_{t-1} - p_{t-1}) \tag{67}$$

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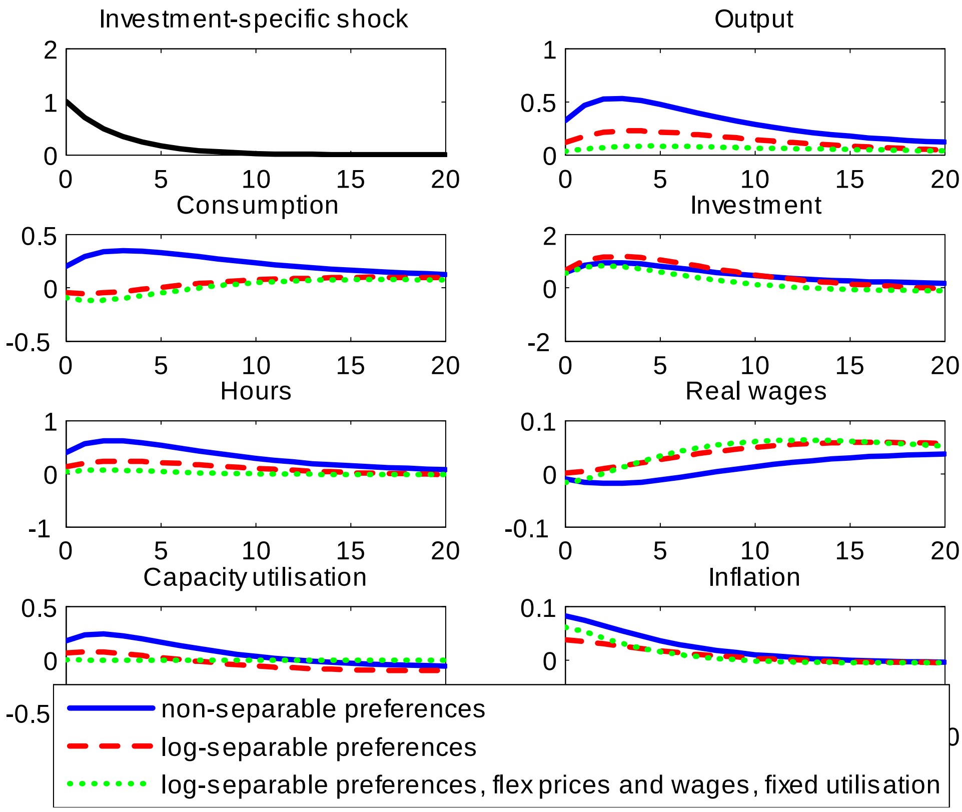

Figure 1: Impulse-responses to an IST shock in the baseline version of our model with different assumptions on preferences, nominal rigidities and variable capacity utlisation

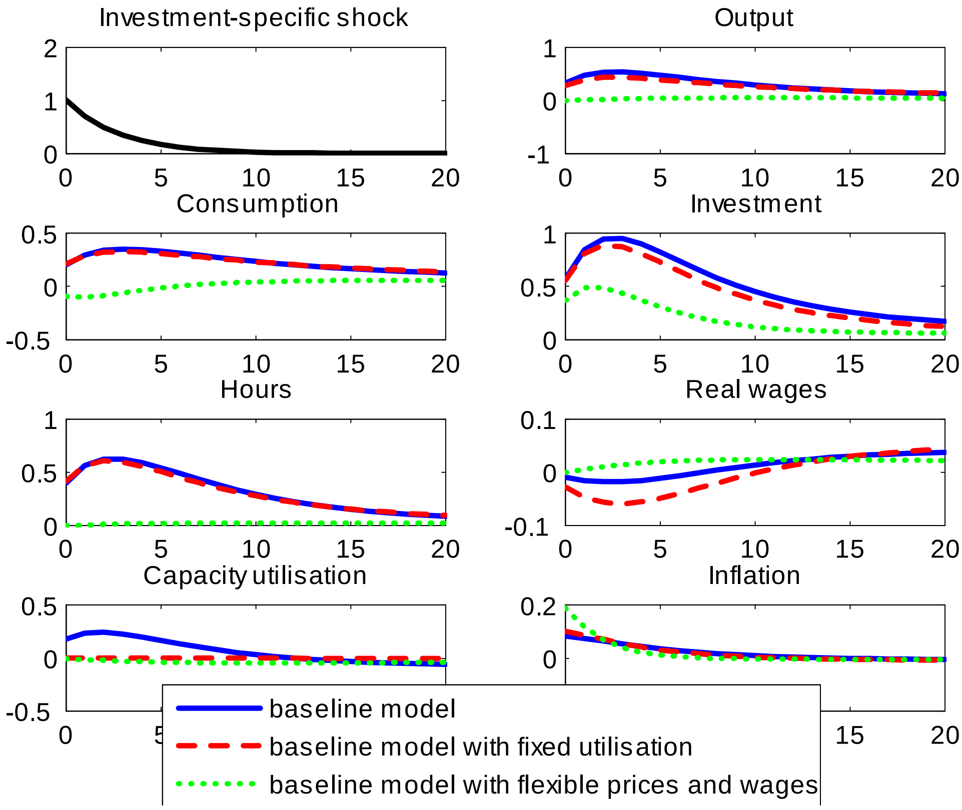

Figure 2: Impulse-responses to an IST shock in the baseline version of our model with different assumptions on nominal rigidities and variable capacity utlisation

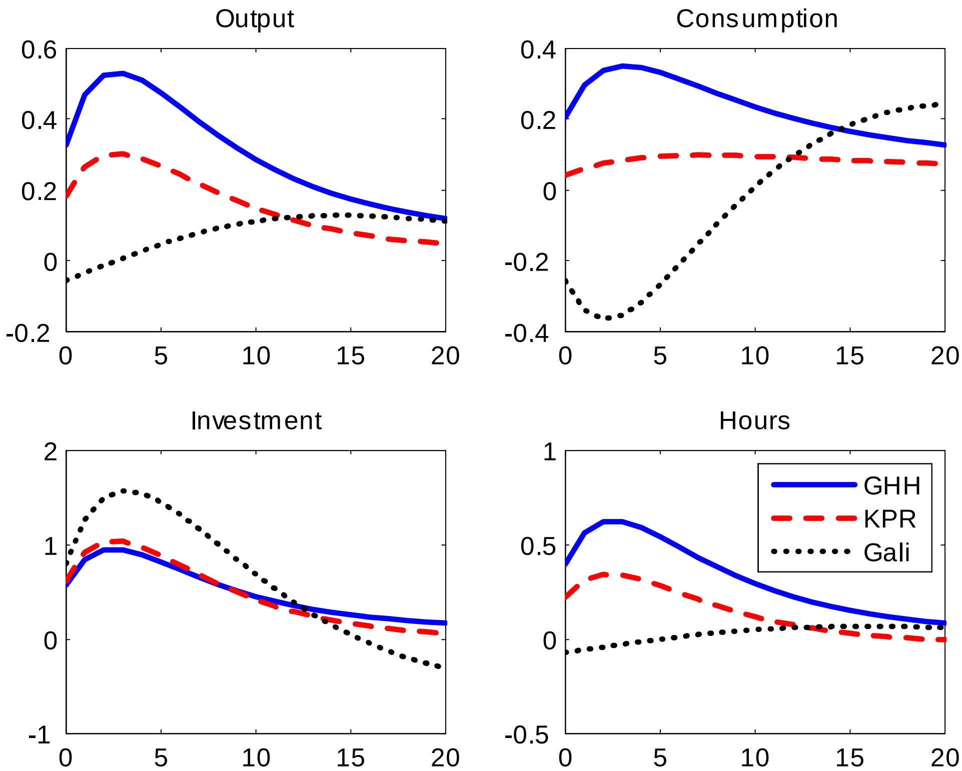

Figure 3: Impulse-responses to an IST shock in the baseline version of our model with different assumptions on preferences

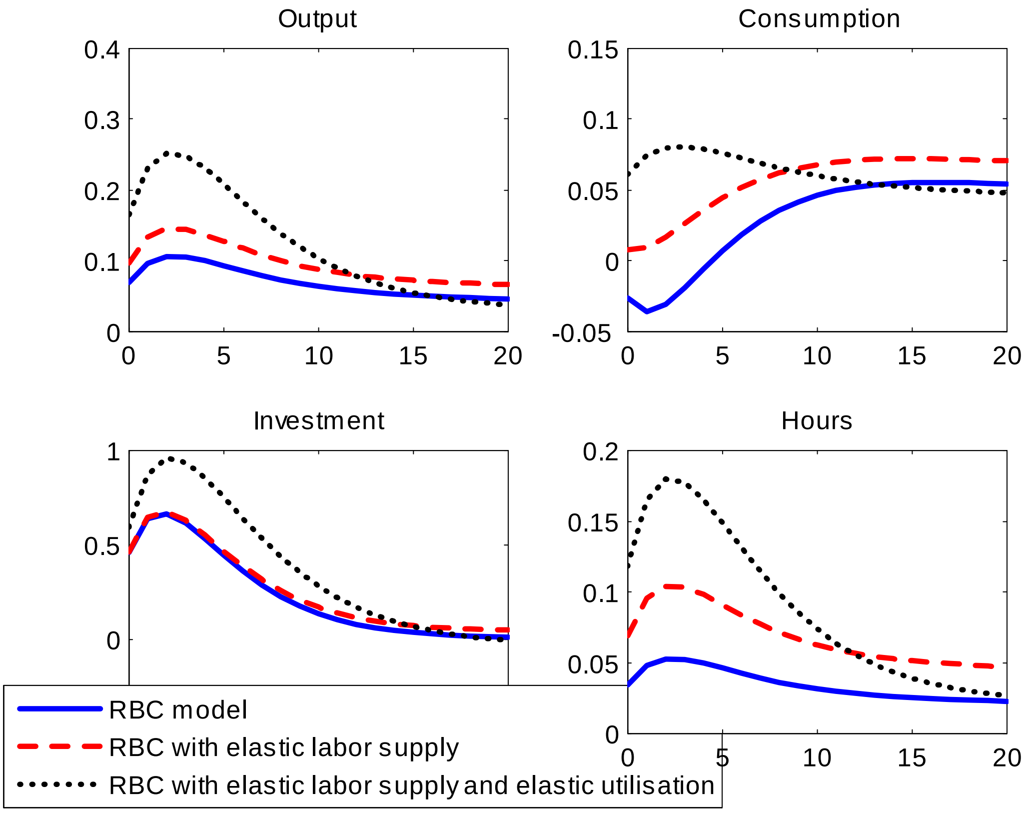

Figure 4: Impulse-responses to an IST shock in the a version of our model with flexible prices and wages

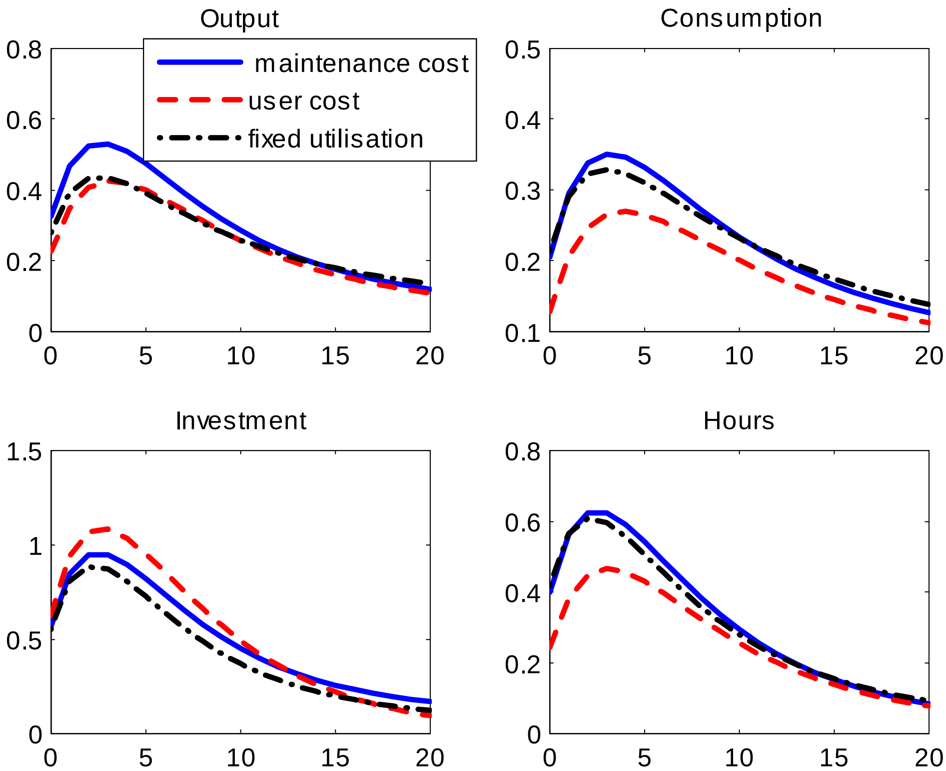

Figure 5: Impulse-responses to an IST shock in the baseline version of our model with different assumptions on variable capacity utlisation