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Abstract

This paper documents a new Search & Matching extension of the basic version of QUEST, the European Commission Dynamic General Equilibrium model used for policy and historical business cycle analysis. The new module is suited for tracking labour market variables such as flows in and out of employment, vacancy rate and job separation rate. It hence is hoped to be useful for deepening the understanding of the processes driving the labour market dynamics including the role of crucial parameters such as the relative bargaining power of workers, replacement rate and the average cost of filling a vacancy. The paper provides a description of the extension, discusses its properties and potential uses and compares the results obtained with the extended version to those from the basic QUEST.

JEL Classification: E00, E32, J64.

Keywords: Search & matching, DSGE modelling, endogenous growth.

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1. INTRODUCTION

Unemployment is one of the most important and salient variables capturing information about the state of the economy on the macro-level, second only to, arguably, GDP. Indeed, due to its zero-one nature, the risk of becoming unemployed is likely to loom much larger for economic agents than the one posed by slowing down GDP or high inflation. Despite this fact most traditional Dynamic Stochastic General Equilibrium (DSGE) models, which today are routinely used as a part of the toolkit of macroeconomists, model the labour market in only most rudimentary fashion, more specifically they do not model the flows in and out of unemployment.

While the basic, one-sector version of QUEST (Ratto et al., 2009) got several extensions in various dimensions (see Roeger et al., 2010, for the version with semi-endogenous growth; Pataracchia et al., 2013, for a version with endogenous default on the housing market, Kollmann et al., 2013 for a version with banking sector, etc.), none of them concerned development of a more detailed labour market module. Against this backdrop, this paper describes a variant of one-sector QUEST version which models employment following the Mortensen and Pissarides' Search & Matching framework (e.g., Mortensen et al, 1994; Pissarides, C.A. 2000). The objective of the extension is to provide a tool for analysing employment stocks and detailed flows from and into employment. The more limited objective of this paper is to document the basic properties of the extended model and indicate the labour market-related concepts that can now be analysed. To facilitate comparison, the calibration of the model is kept as close as possible to the original QUEST.[1] An interesting find is that the Search and Matching extended version of QUEST generates (for some policy shocks) higher real wage rigidities compared to the non-extended version and might thus be a more suitable tool to explain employment fluctuations along the cycle.

As in Gertler et al. (2008), employment is assumed to adjust along the extensive margin. Nominal wages are rigid due to the existence of wage adjustment costs (similar to Christoffel, et al., 2006). The remaining blocks of the model are identical to the standard QUEST version.
In this paper we describe the extension in detail (next section) and provide a set of simulations to standard shocks such as productivity, monetary and risk premium shocks, as well as shocks to parameters specific to this version of the model, like the vacancy costs. The results of the simulations followed by their discussion are given in section 3. The last section concludes.

2. THE MODEL

The model is an extension of a basic version of QUEST (Ratto et al., 2009), which is an estimated model to the euro area using Bayesian estimation techniques. It adds a labour market sector, which is modelled as in Search & Matching literature (Pissarides, 2000). The extension follows the basic version of QUEST by introducing two different types of households: Ricardians, or savers, and Non-Ricardians, or rule-of-thumb consumers. This generalises the classic Search & Matching framework which considers only one type of households (who behave like Ricardians in QUEST). Additionally,

[1] For the same reason, we also keep the description of the extension closer to the spirit of the DSGE literature and do not use some of the more usual notations and concepts typical for the search and matching models. Nevertheless, both, the extension and its the description are equivalent to the corresponding notions of the labour market literature.

the extension introduces nominal wage rigidity assuming quadratic costs of adjustment, similar to (Christoffel et al., 2006).

In this section, only the Search & Matching extension of QUEST is discussed. To find out more about the structure of other parts of QUEST model, the reader is invited to get acquainted with (Ratto et al., 2009).

2.1 PRELIMINARIES

Households are indexed by i on the unit interval, with rule-of-thumb consumers, $i \in [0; slc]$ and savers $i \in (slc; 1]$. Hence, $1 - slc$ is the share of savers in the economy. Following Merz (1995), each household (of any type) consists of a continuum of members, again indexed on a unit interval. In t, both types supply homogenous labour, L_{it}, which is remunerated at the nominal wage rate W_t.

Firms and workers search for one another in a decentralised labour market. In order to employ new workers in t, homogenous, monopolistically competitive (intermediate) goods producers post vacancies V_t, which they hope to get filled through a Poissonian process that takes into account the number of vacancies and the number of unemployed, U_{t-1}, in the previous period. Following the literature, this process is represented by a log-linear matching function of the form:

$$m_t \stackrel{\text{def}}{\equiv} m(U_{t-1}, V_t) = \sigma_m {U_{t-1}}^{\zeta} {V_t}^{1-\zeta} \tag{1}$$

ζ is the elasticity of the matching function with respect to unemployment and $\sigma_m > 0$ represents the matching efficiency. The matching function m_t is increasing and concave in both its' arguments and has constant returns to scale. Furthermore, it is supposed that at least one vacancy and one unemployed person need to be searching in the market for a match to occur, i.e. $m(0, V_t) = m(U_{t-1}, 0) = 0$.

The rate at which the unemployed find job is:

$$f_t \equiv \frac{m(U_{t-1}, V_t)}{U_{t-1}} = \sigma_m \left(\frac{V_t}{U_{t-1}}\right)^{1-\zeta} \geq 0 \tag{2}$$

Similarly, the rate at which vacancies get filled (the probability of filling a vacant job per unit of time) is defined as

$$q_t \equiv \frac{m(U_{t-1}, V_t)}{V_t} = \sigma_m \left(\frac{U_{t-1}}{V_t}\right)^{\zeta} \geq 0 \tag{3}$$

It is assumed that in every period a number of workers is exogenously separated from their employer. The job separation rate, the same for any worker type, is denoted by $\delta_t = \delta_0 e^{\varepsilon_t^{\delta}}$ where $\delta_0 > 0$ and ε_{δ_t} is a job separation shock[2].

[2] In the calibration of this model, we will follow Burda 2016 and assume $\delta = 0.06$, a fixed value which matches the data of the German economy. In reality, the job separation rate varies across the business cycle, typically increasing during recessions and the decision to destroy a job is in effect an endogenous one. For the sake of simplicity, we assume δ to be exogenous but a natural extension of the model would be to adopt an endogenous job destruction decision of the firm.

The total population in the economy (including both types of households) is constant and normalised to 1. For accounting purposes, we introduce a distinction between total population and labour force, consisting of the employed and the unemployed actively searching for employment. The inactive part of the population, N_t, is assumed to be exogenously given and constant, $N_t \equiv N$

$$L_t + U_t = 1 - N_t = 1 - N \tag{4}$$

Given constant labour force $1 - N$, the system of flows in and out of employment and unemployment is:

$$\left\{ \begin{matrix} L_t = (1 - \delta_t)L_{t-1} + m_t \\ U_t = \delta_t L_{t-1} + (1 - f_t)U_{t-1} \end{matrix} \right\}$$

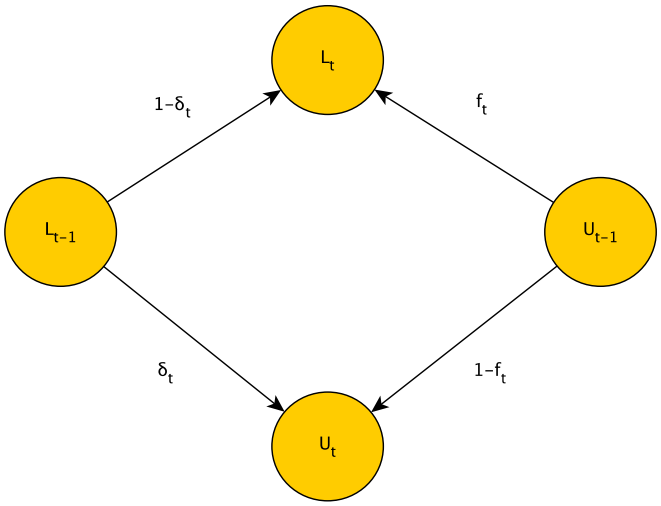
Here the assumption is that most cyclical fluctuations in unemployment are drive by entry and exit from employment while shifts in and out of the labour force are of second order.

The first equation in the system can be conveniently rewritten as:

$$L_t = (1 - \delta_t)L_{t-1} + f_t U_{t-1} = (1 - \delta_t - f_t)L_{t-1} + f_t(1 - N) \tag{5}$$

Note the timing convention, in which stocks at time t (L_t, U_t) indicate the ***end of period*** stocks. The labour flows are visualised on Graph 2.1.

Graph 2.1. **Labour flows**



2.2 HOUSEHOLDS

Following Trigari (2006), it is assumed that on the level of a household's member, labour is indivisible. Hence, an individual family member provides 1 unit of labour when employed and 0

otherwise.[3] The value function of a household (for both, savers and rule-of-thumb consumers), given the aggregated stock of labour provided by its members, is:

$$\Omega(L_{it}) = U(C_{it}) + \beta \mathrm{E}_t[\Omega(L_{it+1})] \tag{6}$$

with $U(C_{it})$ being the instantaneous utility over consumption and $\beta < 1$ a discount factor.

2.2.1. Savers

Savers consume, invest in bonds B_{it} and receive work compensation, firm dividends div_{it} and lump-sum transfers T_t^r from the government. The unemployed also receive unemployment benefits at per capita rate b_t. Therefore, their budget constraint is:

$$\begin{aligned} &\frac{C_{it}^r(1+\tau_t^C)P_t^C}{P_t} + \frac{\mathrm{B}_{it}}{P_t} \\ &\quad = (1-\tau_t^L)\frac{W_t}{P_t}L_{it} + \frac{(1+\mathrm{r}_t)\mathrm{B}_{it-1}}{P_t} + T_t^r + \mathrm{b}_t(1-L_{it}-N) + \mathrm{div}_{it} \\ &\quad - \frac{\gamma^W}{2}\frac{(\Delta \mathrm{W}_t)^2 \mathrm{L}_{it}}{P_t} \end{aligned} \tag{7}$$

with P_t the price level (GDP deflator), P_t^C – consumption deflator, r_t – interest rate and τ_t^C and τ_t^L – consumption and labour taxes, respectively. The last term is the quadratic cost of nominal wage adjustment, as in Christoffel et al. (2006).

By differentiating the value function (6) with respect to labour, L_{it}, subject to the budget constraint (7) and flow identity (5), it can be shown that individual member's value function in monetary terms is, $S_{it}^r \overset{\text{def}}{=} \frac{\partial \Omega_{it}}{\partial \mathrm{L}_{it}} / \lambda_{it}^r$:

$$S_{it}^r = (1-\tau_t^L)\frac{W_t}{P_t} - \frac{\gamma^W}{2}\frac{(\Delta \mathrm{W}_t)^2}{P_t} + \beta \mathrm{E}_t\left[(1-\delta_{t+1}-f_{t+1})\frac{\lambda_{it+1}^r}{\lambda_{it}^r}S_{it+1}^r\right] - \mathrm{b}_t \tag{8}$$

where λ_{it}^r is the Lagrange multiplier on budget constraint (7) and is implicitly defined as:

$$U'(C_{it}) = \frac{\lambda_{it}^r(1+\tau_t^C)P_t^C}{P_t}$$

Equation (8) defines the value S_{it}^r of a Ricardian family member being employed at *t*, which consists of labour income adjusted for taxes and wage adjustment costs and the value of being employed in the same firm in the future, minus the loss of unemployment benefits, $-\mathrm{b}_t$.

2.2.2. Rule-of-thumb consumers

Non-Ricardians every period consume their disposable income, which consists of work compensation, the lump-sum transfers T_{it}^n from the government and unemployment benefits for those family members

[3] Hence, in this framework, hours worked per employee are constant. For a model formulation in which both, the intensive and extensive margins are subject to endogenous choice by agents see, e.g., Trigari (2006).

who do not work. They do not invest in financial assets and do not own firms. Therefore, their budget constraint is:

$$\frac{C_{it}^{n}(1+\tau_{t}^{C})P_{t}^{C}}{P_{t}} = (1-\tau_{t}^{L})\frac{W_{t}}{P_{t}}L_{it} + T_{t}^{n} + \mathrm{b}_{t}(1-L_{it}-N) - \frac{\gamma^{W}}{2}\frac{(\Delta \mathrm{W}_{t})^{2}\mathrm{L}_{it}}{P_{t}} \qquad (9)$$

Differentiating of their value function (6) with respect to labour, L_{it}, subject to the above budget constraint and flow identity (5) leads to the following employment decision equation:

$$S_{it}^{n} = (1-\tau_{t}^{L})\frac{W_{t}}{P_{t}} - \frac{\gamma^{W}}{2}\frac{(\Delta \mathrm{W}_{t})^{2}}{P_{t}} + \beta \mathrm{E}_{t}\left[(1-\delta_{t+1}-f_{t+1})\frac{\lambda_{it+1}^{n}}{\lambda_{it}^{n}}S_{it+1}^{n}\right] - \mathrm{b}_{t}$$

which is analogous to (8) and λ_{it}^{r} is the Lagrange multiplier on budget constraint (9):

$$U'(C_{it}) = \frac{\lambda_{it}^{n}(1+\tau_{t}^{C})P_{t}^{C}}{P_{t}}$$

and

$$S_{it}^{n} \stackrel{\text{def}}{=} \frac{\partial \Omega_{it}}{\partial \mathrm{L}_{it}} / \lambda_{it}^{n} \qquad (10)$$

Equation (10) defines the value $\frac{S_{it}^{n}}{\lambda_{it}^{n}}$ of a non-Ricardian family member being employed at *t*, which consists of labour income adjusted for taxes and wage adjustment costs and the value of being employed in the same firm in the future, minus the loss of unemployment benefits, $-\mathrm{b}_{t}$.

2.2.3. Aggregation

On behalf of individual workers, bargaining with firms over wages is assumed to be carried out by trade unions, which take into account the interests of both types of households. For this reason, it is convenient to aggregate over conditions (10) and (8) to obtain:

$$\mathrm{S}_{t} = (1-\tau_{t}^{L})\frac{W_{t}}{P_{t}} - \frac{\gamma^{W}}{2}\frac{(\Delta \mathrm{W}_{t})^{2}}{P_{t}} + \beta \mathrm{E}_{t}\left[(1-\delta_{t+1}-f_{t+1})\frac{\lambda_{t+1}}{\lambda_{t}}\mathrm{S}_{t+1}\right] - \mathrm{b}_{t}$$

where $\mathrm{S}_{t} = slcS_{it}^{n} + (1-slc)S_{it}^{r}$ and $\lambda_{t} = slc\lambda_{it}^{n} + (1-slc)\lambda_{it}^{r}$.

2.3 FIRMS

A continuum of firms employs workers (both Ricardian and non-Ricardian) and rent capital from savers to produce a differentiated good, which is next combined and used for production of consumption, investment and export goods. The firms are monopolistically competitive; therefore, firm *j* faces the usual demand function for its products:

$$Y_{jt} = \left(\frac{P_{jt}}{P_{t}}\right)^{-\tau} Y_{t} \qquad (11)$$

where Y_{jt} and P_{jt} are demand for products of firm *j* and its individual price, respectively, and Y_t and P_t are the respective economy-wide aggregates, which individual firms take as given.
Output is produced with Cobb-Douglas technology, modified to account for productive public capital, K_t^G, and fixed costs, F_y:

$$Y_{jt} = \left(cu_{jt}K_{jt}\right)^{1-\alpha}\left(z_t\left(L_{jt}-L_0\right)\right)^{\alpha}(K_t^G)^{1-\alpha^G} - z_tF_y \tag{12}$$

where cu_t is capacity utilisation, K_{jt} – capital, z_t – labour-augmenting productivity, L_{jt} – labour demand and L_0 – overhead labour.

Firms are subject to capital, investment and capacity utilisation adjustment costs as well as taxes on operating profits, τ^K, and social security, ssc. The objective of a firm is to maximise the present discounted value of profits, Π_t:

$$\Pi_{jt} = (1-\tau^K)\left(Y_{jt} - (1+ssc)\frac{W_t}{P_t}L_{jt}\right) + \tau^K\delta^K\frac{P_t^K}{P_t}K_{jt} - \frac{P_t^K}{P_t}I_{jt} - a_tV_{jt} - adj\_costs_{jt}$$

where δ^K is capital depreciation rate, P_t^K is the price of capital, I_{jt} – investment and the adj_costs_{jt} term groups together the various adjustment costs the firm faces. Finally, a_t is the cost per vacancy published by the firm.

Denote R_{jt} the value function of firm *j*:

$$R\left(L_{jt};\Gamma_{jt}\right) = \Pi_{jt} + \beta\mathrm{E}_t\left[\frac{\lambda_{t+1}^r}{\lambda_t^r}R\left(L_{jt+1};\Gamma_{jt+1}\right)\right]$$

where Γ_{jt} groups state variables other than labour. Note that the firm discounts its future profits with a discount factor of the Ricardians, since they are the ultimate and only owners of all the firms. The firm's optimisation is subject to demand equation (11), production function (12), labour flow equation (5) which, from the firm's perspective takes the form of:

$$L_{jt} = (1-\delta_t)L_{jt-1} + q_tV_{jt}$$

and capital accumulation equation:

$$K_t = (1-\delta^K)K_{t-1} + I_t$$

The first order condition with respect to labour then implies:

$$\frac{a_t}{q_t} = (1-\tau^K)\left(\alpha\eta_t\frac{Y_{jt}+z_tF_y}{L_{jt}-L_0} - (1+ssc)\frac{W_t}{P_t}\right) + \beta\mathrm{E}_t\left[\frac{\lambda_{t+1}^r}{\lambda_t^r}(1-\delta_{t+1})\frac{a_{t+1}}{q_{t+1}}\right] \tag{13}$$

where $\eta_t = 1 - \tau - \varepsilon_\eta - sfp\beta E_t \frac{\Delta P_{t+1}}{P_t} - (1 - sfp)\frac{\Delta P_{t-1}}{P_{t-2}} + \frac{\Delta P_t}{P_{t-1}}$ is the inverse of the firm's mark-up of prices over wages (firms are monopolistically competitive), with $0 \leq sfp \leq 1$. This condition is best interpreted in terms of vacancies posted by a firm. Firms post as many vacancies so to equalise the cost of a filled vacancy (which is the cost of a posted vacancy divided by the rate at which vacancies are filled) with the future surplus due to the vacancy being filled. The latter is equal to the additional product obtained from having one more worker, net of wage costs, plus the benefit of not having to fill this vacancy in the future (the last term on the right-hand-side). This latter benefit is diminished due to an exogenous worker separation rate, δ_{t+1}.

All firms being identical in the equilibrium, we can drop indices *j* from the optimality condition (13). Hence, the surplus of a firm from a filled vacancy:

$$J_t \equiv (1 - \tau^K)\left(\alpha\eta_t \frac{Y_t + z_t F_y}{L_t - L_0} - (1 + ssc)\frac{W_t}{P_t}\right) + \beta \mathrm{E}_t \left[\frac{\lambda^r_{t+1}}{\lambda^r_t}(1 - \delta_{t+1})\frac{a_{t+1}}{q_{t+1}}\right]$$

2.4 WAGE BARGAINING

Once the vacancies are filled, a bargaining process commences in order to establish the wages paid to the newly-hired workers. As is most common in the literature (Mortensen et al., 1994), in this paper it is assumed that the benefits from filling a vacancy are split according to Nash bargaining. Hence, the optimal wage W_t^*solves:

$$W_t^* = \arg\max_{W_t}(\mu_t \log S_t + (1 - \mu_t)\log J_t)$$

where $\mu_t = \mu_0 e^{\varepsilon_t^\mu}$, measures the unions' relative bargaining power and ε_t^μ is a bargaining power shock.[4]

The first order condition gives:

$$S_t = -\frac{\mu_t}{1 - \mu_t}\frac{(\partial S_t/\partial W_t)}{(\partial J_t/\partial W_t)}J_t \qquad (14)$$

with

$$\partial J_t/\partial W_t \equiv -(1 - \tau^K)(1 + ssc)\frac{1}{P_t}$$

$$\partial S_t/\partial W_t \equiv (1 - \tau_t^L)\frac{1}{P_t} - \gamma^W \frac{\Delta \mathrm{W}_t}{P_t} + \gamma^W \beta \mathrm{E}_t \left[(1 - \delta_{t+1} - f_{t+1})\frac{\lambda_{t+1}}{\lambda_t}\frac{\Delta \mathrm{W}_{t+1}}{P_{t+1}}\right]$$

Wage condition (14) is rather hard to interpret in its current form. To gain some insight into this equation, it is worth for the time being to disregard the existence of wage adjustment costs. In this case, condition (14) can be transformed to obtain:

[4] It is assumed that both types of households have the same relative bargaining power.

$$S_t = \frac{\mu_t}{1-\mu_t}\frac{(1-\tau_t^L)}{(1-\tau^K)(1+ssc)}\frac{a_t}{q_t}$$

This can be plugged into the households' surplus function after bargaining which, upon re-arranging, yields:

$$\frac{\mu_t}{1-\mu_t}\frac{(1-\tau_t^L)}{(1-\tau^K)(1+ssc)}\left((1-\tau^K)\left(\eta_t MPL_t - (1+ssc)\frac{W_t}{P_t}\right) + \beta \mathrm{E}_t\left[\frac{\lambda_{t+1}^r}{\lambda_t^r}(1-\delta_{t+1})\frac{a_{t+1}}{q_{t+1}}\right]\right) + \mathrm{b}_t$$
$$= (1-\tau_t^L)\frac{W_t}{P_t} + \beta \mathrm{E}_t\left[(1-\delta_{t+1}-f_{t+1})\frac{\lambda_{t+1}}{\lambda_t}\frac{\mu_{t+1}}{1-\mu_{t+1}}\frac{(1-\tau_{t+1}^L)}{(1-\tau^K)(1+ssc)}\frac{a_{t+1}}{q_{t+1}}\right]$$

Upon making a further simplification that all the taxes as well as bargaining power, μ_t, be constant over time and that Ricardians be the only households in the economy, we obtain the standard in the Search & Matching literature expression for wages:

$$\frac{W_t}{P_t} = \frac{\mu}{(1-\tau^K)(1+ssc)}\left((1-\tau^K)\eta_t MPL_t + \beta \mathrm{E}_t\left[\frac{\lambda_{t+1}^r}{\lambda_t^r} f_{t+1}\frac{a_{t+1}}{q_{t+1}}\right]\right) + \mathrm{b}_t\frac{1-\mu}{1-\tau^L} \quad (15)$$

where $MPL_t = \alpha\frac{Y_t + z_t F_y}{L_t - L_0}$ is the marginal product of labour (as a reminder, $\eta_t = 1-\tau-\varepsilon_\eta - sfp\beta E_t\frac{\Delta P_{t+1}}{P_t} - (1-sfp)\frac{\Delta P_{t-1}}{P_{t-2}} + \frac{\Delta P_t}{P_{t-1}}$). The worker receives labour compensation which is a weighted average of the outside option – the benefit rate, b_t, and the surplus from being employed. The surplus depends on the households' relative bargaining power, μ, and consists of the marginal product of labour, MPL_t, and a part of the additional future surplus due to the vacancy being filled. If the worker has full bargaining power ($\mu = 1$) then he will be entitled to a wage rate equal to his marginal productivity and to future expected flows from a filled vacancy. If on the contrary the worker has no bargaining power ($\mu = 0$) he will have to resort to earning his reservation wage b_t, the benefit replacement rate. The expression is analogous to that found, e.g. in Burda and Weder (2016).

The real wage of the QUEST version without search and matching frictions is algebraically long and in our view not very instructive to present here, we thus opt for a generalised expression:

$$\frac{W_t}{P_t} = F(C_t, L_t, b_t)$$

In this wage expression, a trade union sets wages by maximising a weighted average of the utility functions of savers and rule-of-thumb consumers. It is obtained by equating a weighted average of the marginal utility of leisure to a weighted average of the marginal utility of consumption times the real wage of the two household types, adjusted for a wage mark-up, which is set over the household's reservation wage.

The reservation wage is the ratio of the household's marginal disutility of working over its marginal utility of consumption (represented in the expression of the wage rate, but not shown here, by the λ_t and λ_{t+1} terms). If this ratio is equal to the wage the household receives when employed, he will be indifferent between working or being unemployed[5]. Fluctuations in the wage mark-up arise because of

[5] Note that in this model version without search and matching frictions, there is no distinction between being an inactive worker and being an unemployed worker, which is equivalent to postulating that $N_t = U_t$ in the extended model version.

wage adjustment costs and due to the fraction of households $0 \leq 1 - sfw \leq 1$ that index the growth rate of wages and prices to the same growth rates of the previous period.

The main components of the real wage rate of the non-extended QUEST version are the marginal utility of consumption, the marginal disutility of labour and the benefit replacement rate, all of which influence the wage with positive sign. In the real wage expression of the search and matching version, as productivity increases, so does the marginal product of labour, MPL_t, and workers need to be compensated by a higher wage rate. The wage expression of the non-extended QUEST version does not explicitly depend on productivity but does depend on consumption per capita which also drives the wage upward. The benefit replacement rate in both wage expressions, of the extended and non-extended model, make the outside option of the worker more appealing, its' increase needs thus to be accompanied by a rise in the real wage rate.

The main difference between these two wage rates is the presence of the marginal product of labour and a part of the future surplus from having a filled vacancy, $\beta \mathrm{E}_t \left[\frac{\lambda_{t+1}^r}{\lambda_t^r} f_{t+1} \frac{a_{t+1}}{q_{t+1}}\right]$, in the search and matching wage which is not present in the non-extended QUEST version. These terms which are specific to firms appear in the worker's wage rate trough the bargaining process in which the worker and the firm are involved via relative bargaining powers μ and $1 - \mu$, respectively. In the non-extended QUEST version there is no bargaining process taking place, the trade union sets the wage in the way explained above. The ratio of the marginal utility of leisure over the marginal utility of consumption which is present in the standard QUEST version, is not present in the search and matching extension.

3. UNDERSTANDING PROPAGATION OF SHOCKS IN THE MODEL

In this section, the propagation mechanisms of several typical economic shocks in the model are discussed using the standard instrument of impulse-response functions (IRFs). Where possible, a given shock's propagation in the Search & Matching extension of QUEST is compared to that in the basic version of QUEST. For two simulations (temporary TFP shock and monetary shock) a version of QUEST without labour adjustment costs is included to show the role that adjustment costs play in order to mimic search and matching frictions. Before we pass to this analysis, the next subsection explains the calibration of the model.

3.1 CALIBRATION

The Search & Matching extension of QUEST shares most variables and parameter values with its' baseline version. A two-pronged approach is used to calibrate QUEST: First, most parameters that have an impact on the steady state of the model (like the average investment risk premium or the fixed costs in the production function) are generally chosen to make the steady state of certain variables in the model match the average empirical value of their counterparts (e.g. the borrowing rate or investment-to-GDP ratio). Several important empirical values matched by the variables in the model are given in Table 3.1. Second, the remaining parameters from this class (the strength of habits, the share of rule-of-thumb consumers, etc.) and parameters that only influence the dynamics of the model (elasticities, adjustment costs parameters etc.) are chosen following micro-studies and other modelling literature. The most important of these parameters are reported in Table 3.2.

Table 3.1. **Empirical ratios matched by the model**

Parameter	Value
C/Y	0.59
I/Y	0.18
T^r/Y	0.16

Table 3.2. **Calibrated parameters**

Parameter	Value	Remark
Consumers		
σ	1	Logarithmic utility over consumption
h	0.7	Strength of habits
slc	0.4	Share of rule-of-thumb consumers
Firms		
α	0.65	
α^G	0.91	
F_y	0.12	Fixed production costs
L_0	0.04	Set to obtain $U_{SS} = 5\%$
τ	0.25	
γ^p	19.75	Price cost adjustment parameter
Labour market		
N	0.29	Share of inactive workers
brr	0.4	Unemployment benefits replacement rate
δ	0.06	Job separation rate
μ	0.77	Workers relative bargaining power
aV/Y	0.005	Vacancy cost share out of GDP
γ^w	235	Wage cost adjustment parameter
γ^L	0	Labour cost adjustment parameter
ζ	0.5	Elasticity of the matching function wrt unemployment
Taxes		
τ^C	0.25	
τ^K	0.27	
τ^L	0.15	
ssc	0.15	
Others		
β	0.01	
Δ	0.015	Depreciation rate of capital
ρ	0.95	The AR(1) coefficient for shocks

The Search & Matching extension of QUEST introduces several parameters that are absent in the baseline version. Following Burda and Weder (2016) the strategy of calibrating these parameters is as follows: As is standard in the literature, it is assumed that the matching function is of Cobb-Douglas type. Workers bargaining power μ is set at 0.77. This parameter has been chosen to generate relatively high wage share characteristic for the European economy. From the steady state of equation (5), one is able to obtain the steady state value of the finding rate as the value of the steady state separation rate, δ, in the equation is assumed to be 0.06 and the labour and the unemployment share are set so as to match the data for these respective variables. Knowing the steady state value of the finding rate, one can obtain the steady state value of the vacancy share by making use of equation (2) and in consequence, by using (3), one can get the steady state value of the vacancy filling rate. In

Burda, M. C and Weder (2016), the steady state cost per vacancy, *a*, is chosen in such a way that the steady state vacancy cost share in GDP is *aV/Y = 0.005*. Finally, two more parameters require additional comment:
First, the baseline version of QUEST has costly adjustment of labour, which is introduced to proxy the sluggish adjustment of labour demand observed in the economy. Since the Search & Matching extension offers an alternative, micro-founded, mechanism for capturing this sluggishness, labour adjustment costs have been removed from that model. The labour adjustment cost parameter in the baseline version of QUEST is then calibrated in this paper so that the trough of labour in both models following a positive temporary TFP shock has an approximately identical depth ($\gamma^L = 15$).

Second, the different approaches to modelling the wage-setting mechanism in both models makes the parameters governing the strength of nominal wage adjustment costs (γ^w in Table 2) incomparable with each other. The strategy here has been to keep the original value of this parameter in the baseline version of QUEST ($\gamma^w = 100$). In the extension, the value of this parameter is chosen such that the trough of nominal wage in both models following a positive temporary TFP shock has an approximately identical depth this procedure resulted in $\gamma^w = 235$ in the extended model.

Unless stated otherwise and following Ratto et al., 2009, the simulations below are all based on a 1% initial shock (the magnitude of the shocks is given by the posterior estimate of one standard deviation of the shock). The shocks follow autoregressive processes of order 1 with the persistence parameter $\rho = 0.95$. The shocks are represented in % deviations from the baseline (except lump sum taxes which are expressed in % of GDP and hence their IRF is expressed in pp deviations from the baseline) and are represented in the figures below. For the simulations of the TFP and the monetary shock, the S&M extension is compared with the baseline QUEST version with and without adjustment costs to see the degree of the latter parameters importance in representing sluggishness on the labour market. The following table lists the variables to which will be affected by the socks:

Table 3.3. **Variables affected by shocks**

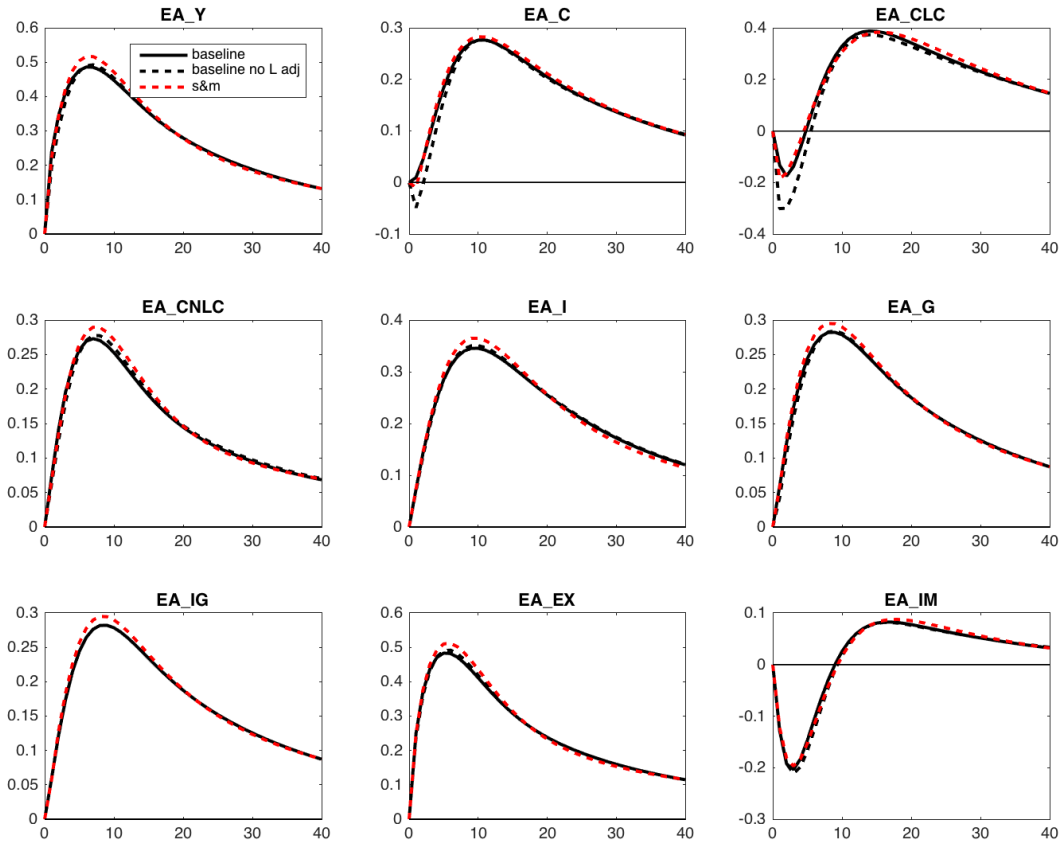
EA_Y	Output
EA_C	Aggregated consumption
EA_CNLC	Consumption of savers
EA_I	Investment
EA_G	Government consumption
EA_IG	Government investment
EA_EX	Exports
EA_IM	Imports
EA_TBY	Trade balance
EA_E	Exchange rate

EA_PY	Output prices
EA_INOM	Nominal interest rate
EA_R	Real interest rate
EA_TAX	Lump sum tax on consumption (% of GDP)
EA_L	Total employment
EA_W	Wage rate
EA_WR	Real wage rate
EA_U	Total unemployment
EA_FIND	Job finding rate
EA_FILL	Vacancy filling rate
EA_VAC	Vacancy rate

3.2 TFP SHOCK

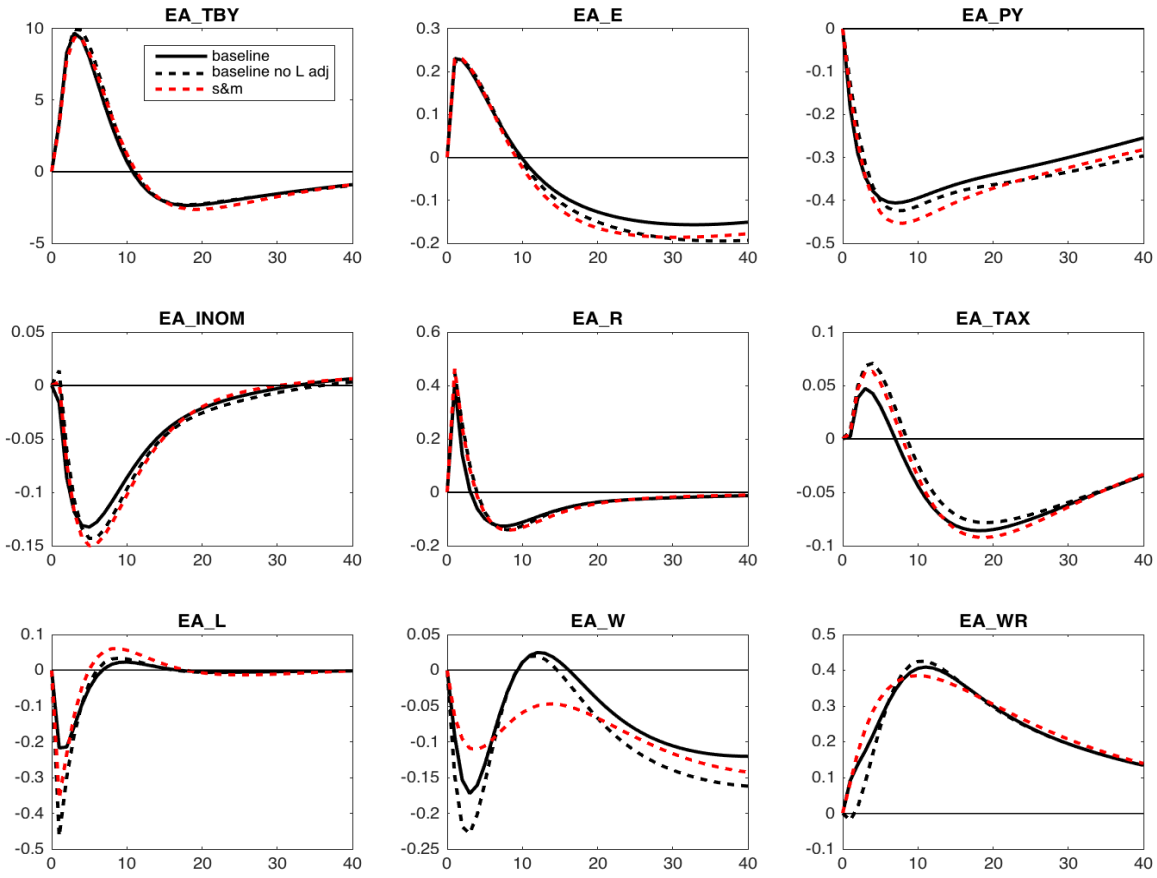
Temporary (persistent) TFP shock (Graphs 3.1-3.3) temporarily increases output, consumption, investment as well as government spending. Prices (temporarily) fall, leading to boost in exports and trade balance improvement and nudging the central bank to decrease the nominal interest rate. Expecting higher consumption and output in the future, labour demand temporarily drops. Real wages increase, but not enough to compensate the rule-of-thumb consumers for dropping current income. For this reason, their consumption initially falls, to start strongly increasing only several quarters later. [6] Firms lower prices insufficiently as a response to a cost-reducing shock, there is a lack of aggregate demand which makes it optimal for individual firms to lower employment.

Graph 3.1. **Temporary TFP shock** (1)



[6] Rule-of-thumb consumers' consumption directly depends on their current income, consisting of wage income and transfers, minus taxes. Ricardian consumers are able to smooth and increase private consumption due to additional sources of income, in particular, increased dividends.

Graph 3.2. **Temporary TFP shock** (2)

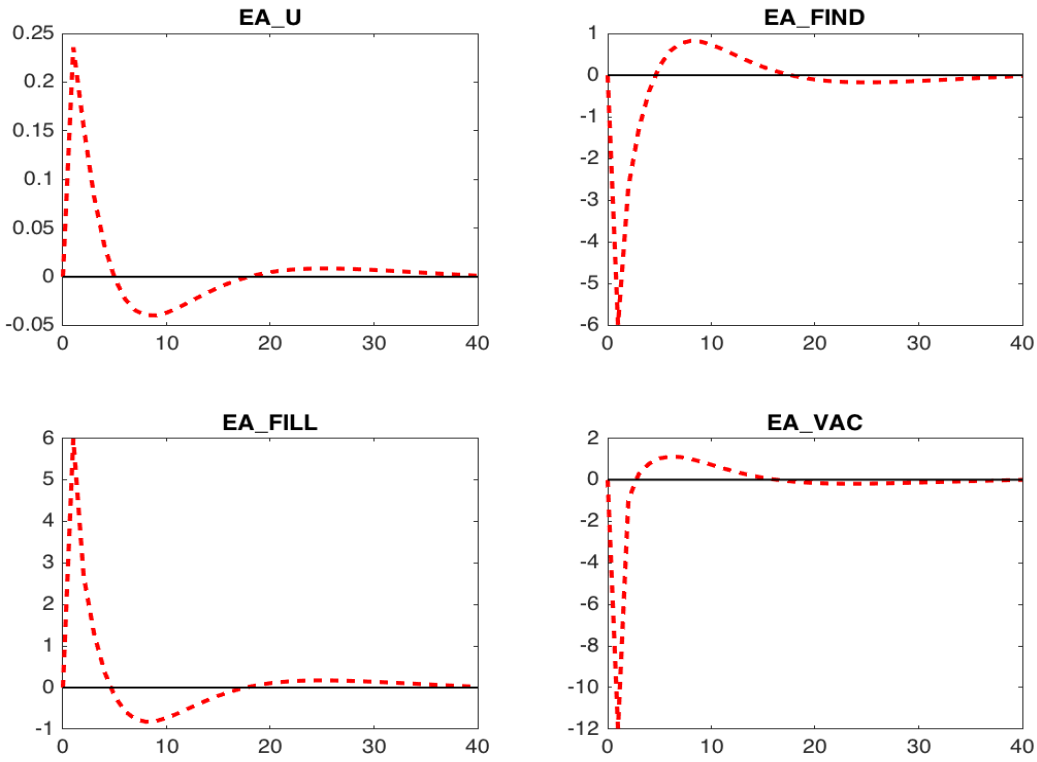


The labour module in the Search & Matching extension gives a further insight into adjustment on the labour market. The initial drop in labour demand is reflected by a brief fall in vacancies (Graph 3.3) posted by the firms. The filling rate initially increases as more potential workers seek employment, while the finding rate necessarily falls and unemployment briefly increases. These effects are later reversed as real wages fall following price adjustment leading to a temporary employment boom.

From inspecting the three curves on the graphs for most variables (the solid line being the baseline QUEST, the black dashed line being the baseline QUEST without labour adjustment costs and the red dashed line being the search and matching extension) it can be seen that as labour adjustment costs decrease, the QUEST model behaves more similar to the search and matching extension (this is however not so clearly the case for nominal and real wages). This can be particularly seen in the behaviour of labour, where its' drop in absolute value is increased as frictions decrease. This is intuitive as the higher labour market frictions/labour adjustment costs, the costlier it is for the firm to adjust labour and thus the less labour reacts to shocks.

As far as nominal wages are concerned, the relationship between labour adjustment costs and similarity between models is reversed: The standard QUEST model behaves more similar to the S&M extension than the QUEST version with labour adjustment costs switched off. Nevertheless, it still holds true that the QUEST version with adjustment costs shows less variation than the version without adjustment costs. Real wages diverge less between the three model versions as in these latter prices evolve similarly.

Graph 3.3. **Temporary TFP shock** (3)

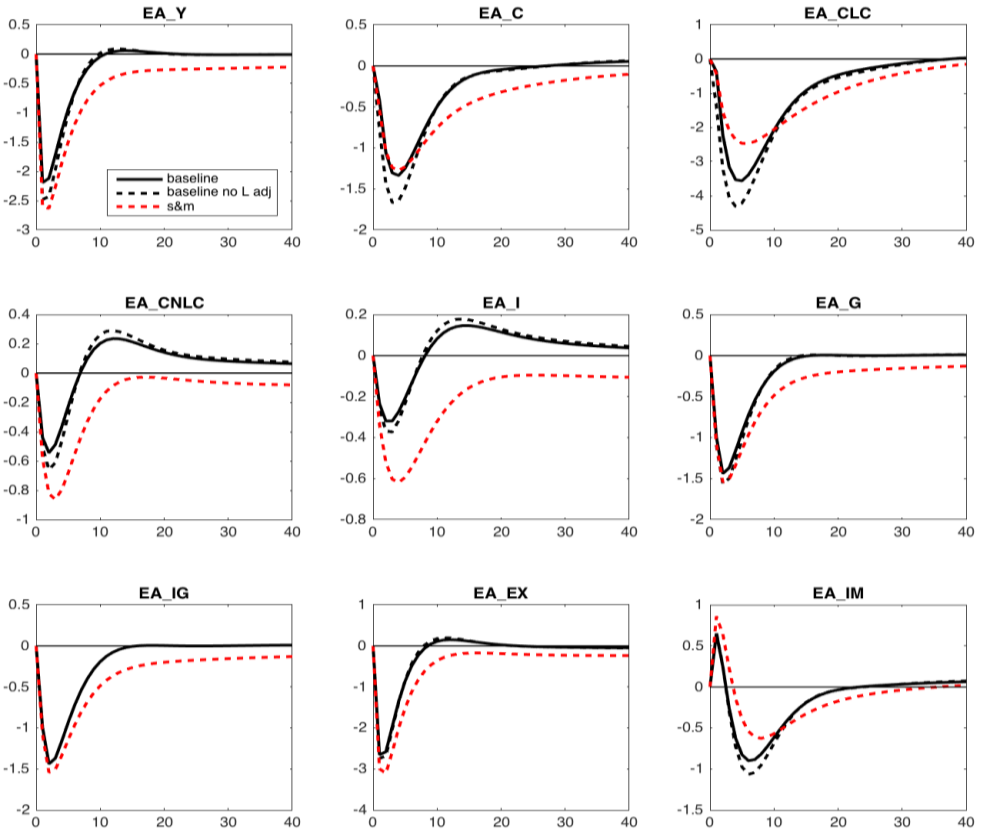


3.3 MONETARY POLICY SHOCK

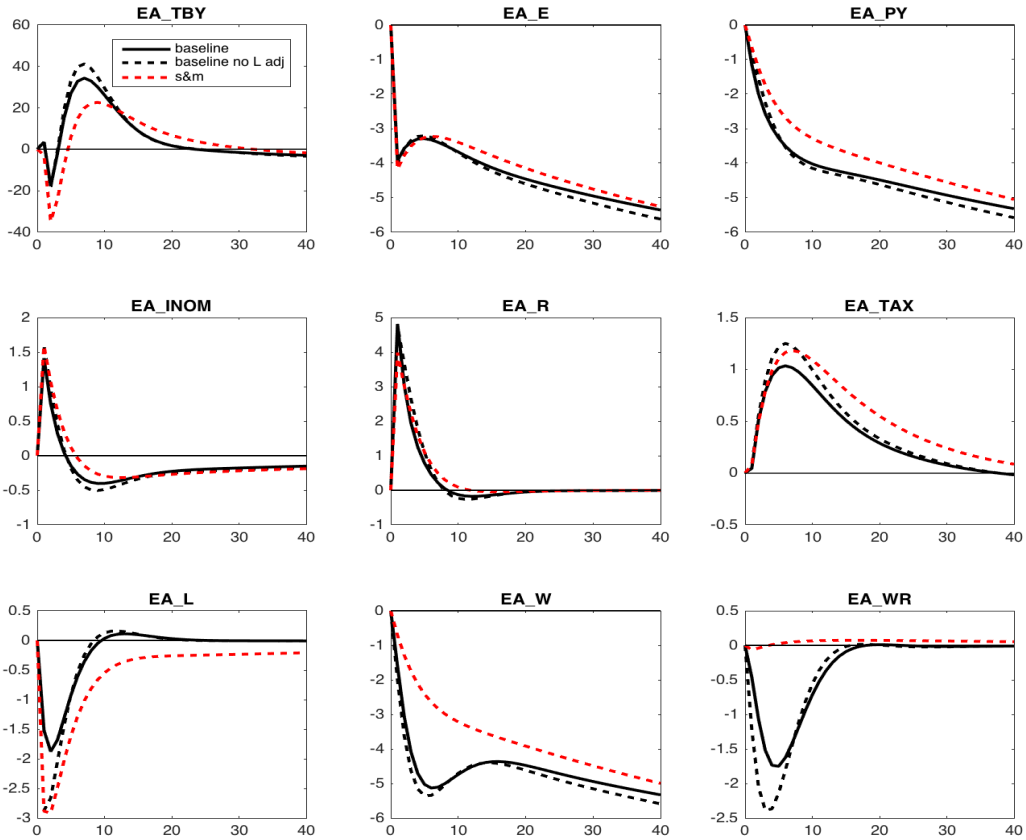
An increase in the nominal interest rate (Graphs 3.4-3.6) leads to a fall in prices, which adjust sluggishly. Due to sluggish adjustment, real interest rates rise, making investment temporarily expensive. As a consequence, output, consumption, investment and government spending all fall. Firms reduce demand for labour, which results in falling wages and employment. In the medium term, the trade balance improves as demand for imported goods falls faster than exports. Real wages of the QUEST model fluctuate a lot compared to those of the search and matching extension which remain almost stable. The reason for the quasi-inertia of real wages in the search and matching extension of the QUEST model is that the real wage rate of the search and matching extension depends on output per employment (Y/L) whereas the wage rate of the non-extended version responds to consumption per capita. Since Y and L move in the same direction after the shock and consumption and population (the number of households) do not, we see that real wages in the search and matching version of the model do not vary much (they are almost rigid) compared to real wages of the non-extended version who show to be very elastic.

For the remaining variables, they stabilise faster in the baseline QUEST versions (with and without labour adjustment costs) compared to the search and matching extension.

Graph 3.4. **(Negative) monetary policy shock** (1)



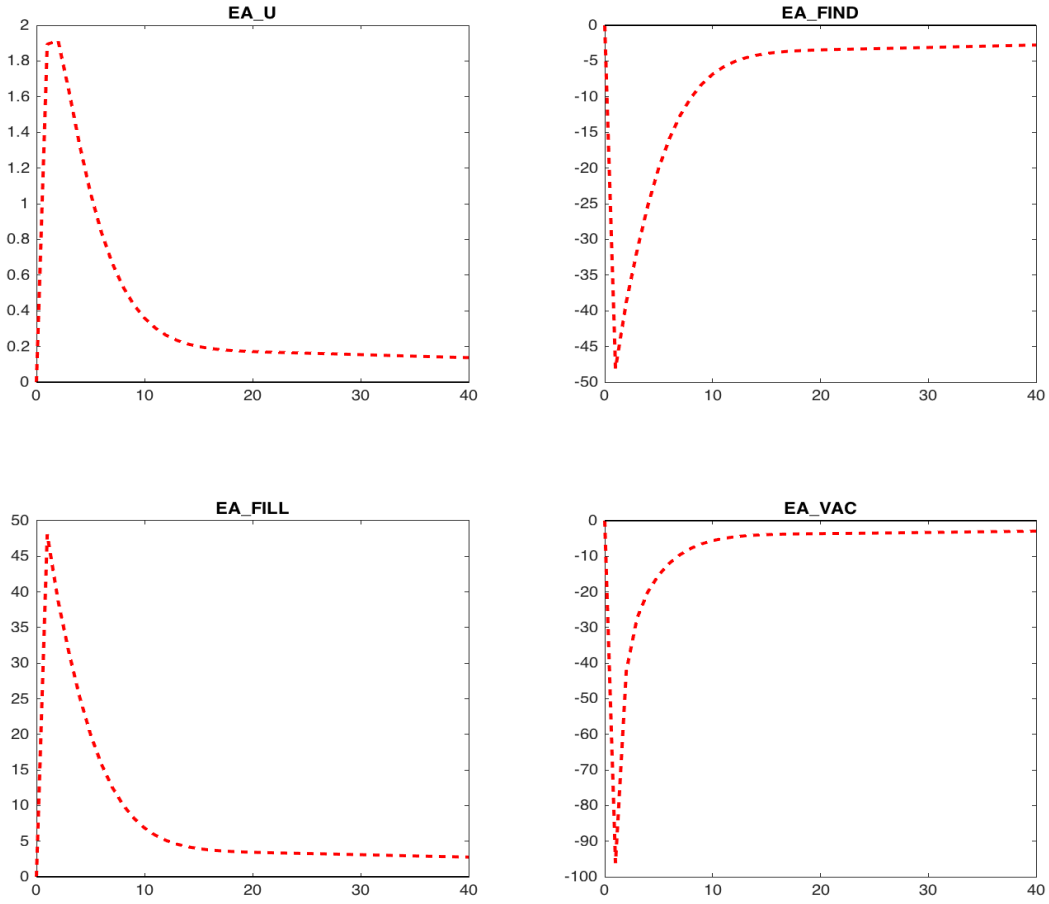
Graph 3.5. **(Negative) monetary policy shock** (2)



When comparing the three model versions (the baseline QUEST, the baseline QUEST without labour adjustment costs and the search and matching extension), one can see that for the majority of cases, labour adjustment costs approximate the search and matching version and the QUEST version as the curves behave more similarly to each other than the curves of the QUEST version without adjustment costs. The higher the adjustment costs for labour, the lesser variables react to shocks.

Turning to the labour market in the in Search & Matching extension, we see that following a hike in nominal rates, firms cut posted vacancies. Consequently, the unemployment rate increases, leading to a higher filling rate and lower finding rate.

Graph 3.6. **(Negative) monetary policy shock** (3)

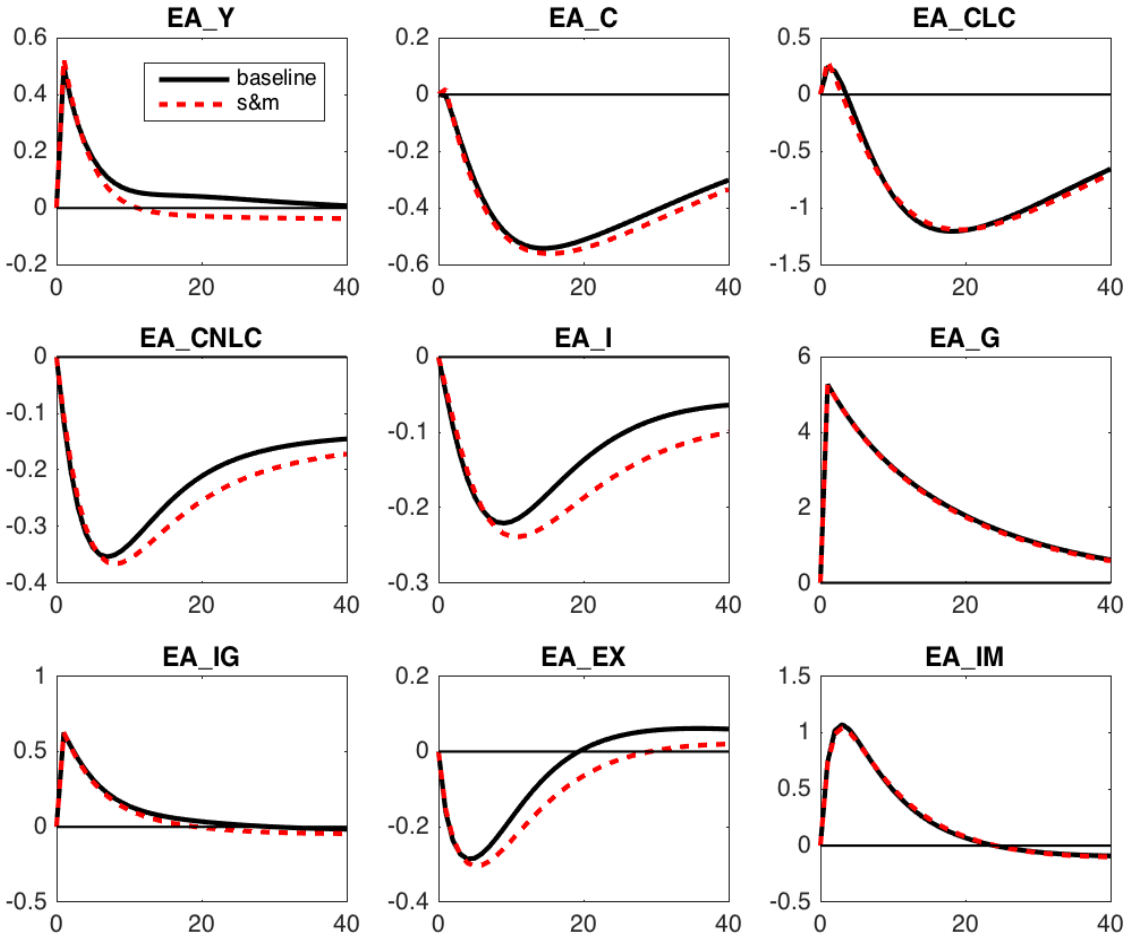


3.4 GOVERNMENT SPENDING SHOCK

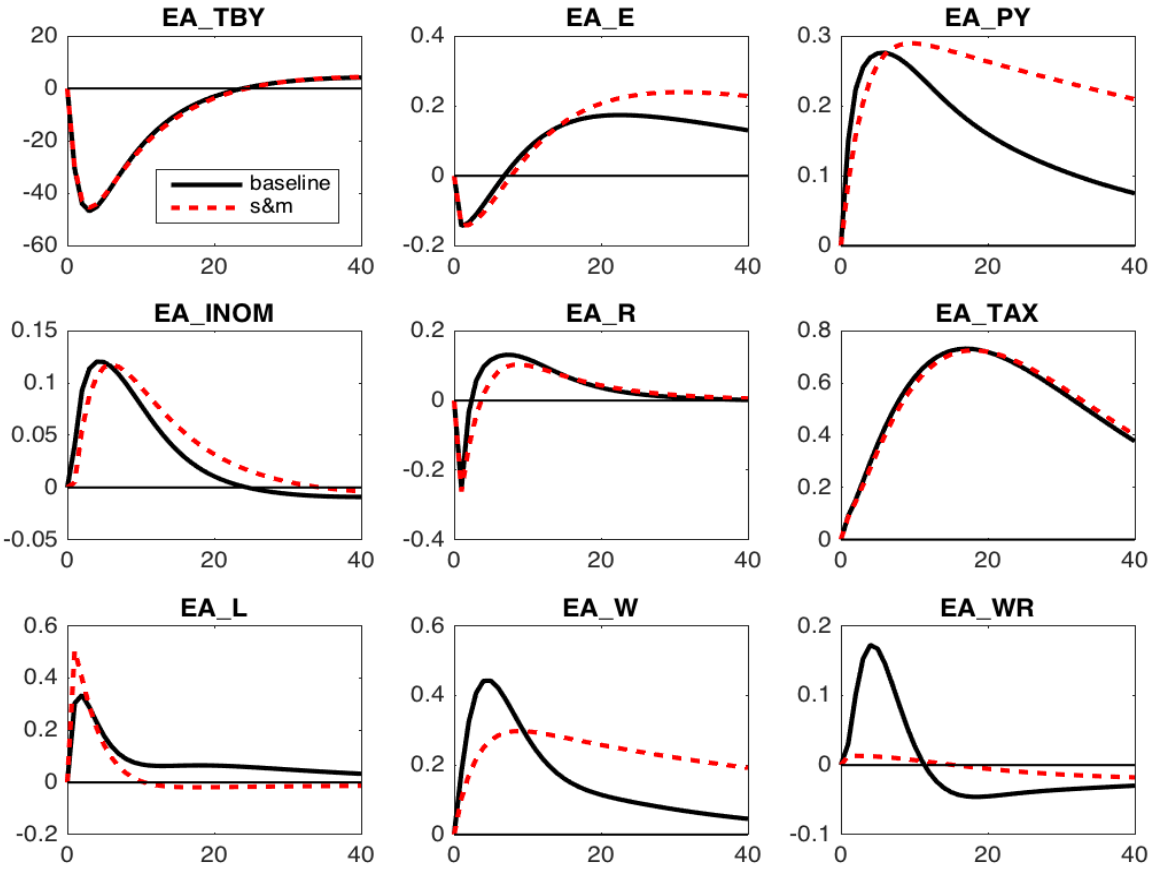
A positive government spending shock increases output due to short-term demand effect, with a short-term multiplier of about 0.5. Private consumption and investment are crowded out while consumption of liquidity constrained households rises in the short run due to increases of wages. In the medium and long run, however, consumption of rule of thumb consumers decreases due to an increase in lump-sum taxes necessary to finance government spending.

As was the case with the monetary shock, real wages in the QUEST model fluctuate more than those of the search and matching extension which remain pretty constant. The reason for the latter is similar to the one written for the monetary shock, namely the response of real wages in the search and matching version to Y and L who move similarly thus creating real wage inertia vis-à-vis the response of real wages of the non-extended model to consumption per capita, the latter not moving equivalently, thus generating more movement of real wages along the cycle.
Due to increased demand, prices and wages increase while trade balance worsens. Labour demand also increases following the short-lived boom. Finally, the central bank reacts by increasing interest nominal rates.

Graph 3.7. **Government spending shock** (1)

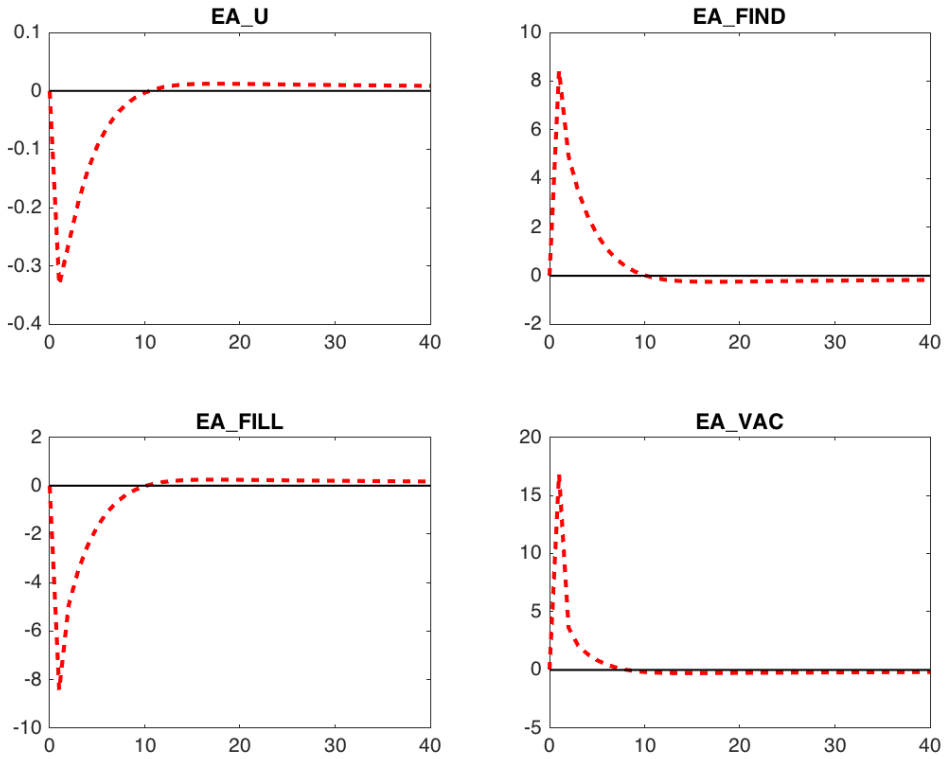


Graph 3.8. **Government spending shock** (2)



The Search & Matching extension shows that a temporary boom created by expansionary fiscal policy reduces unemployment, increases the number of vacancies posted, decreases the filling rate and improves the finding rate.

Graph 3.9. **Government spending shock** (3)

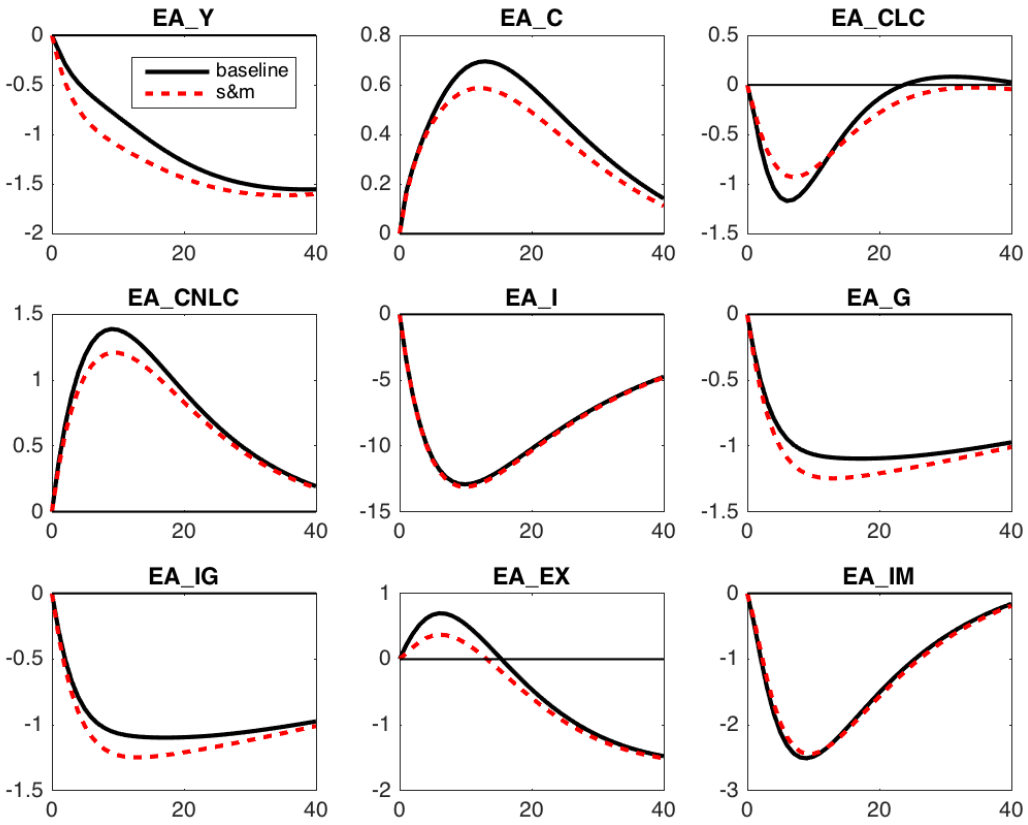


3.5 RISK PREMIUM SHOCK

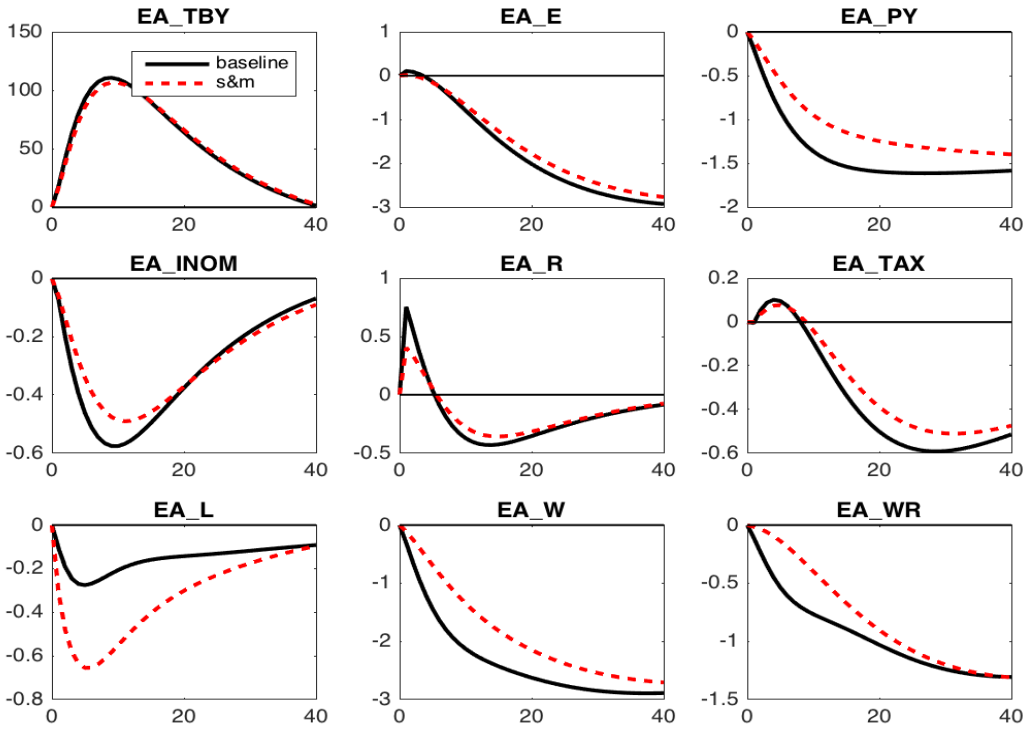
A hike in the risk premium captures the situation in which the cost of investment increases, either due to a higher (possibly only perceived) riskiness in the economy, or due to a lesser willingness to lend in the financial sector (resulting in lower demand for equity and more expensive credit).

This type of shock leads to a strong and persistent fall in private investment. GDP falls, inciting government to cut spending. Private consumption is crowded in, but not enough to stop the fall in GDP. Interestingly, the boost of aggregate consumption is entirely due to Ricardian households cutting investment. The disposable income of non-Ricardians falls (due to falling wages and employment), which forces them to consume less. Typical for recessions, prices and nominal interest rates fall, while trade balance improves.

Graph 3.10. **Risk premium shock** (1)

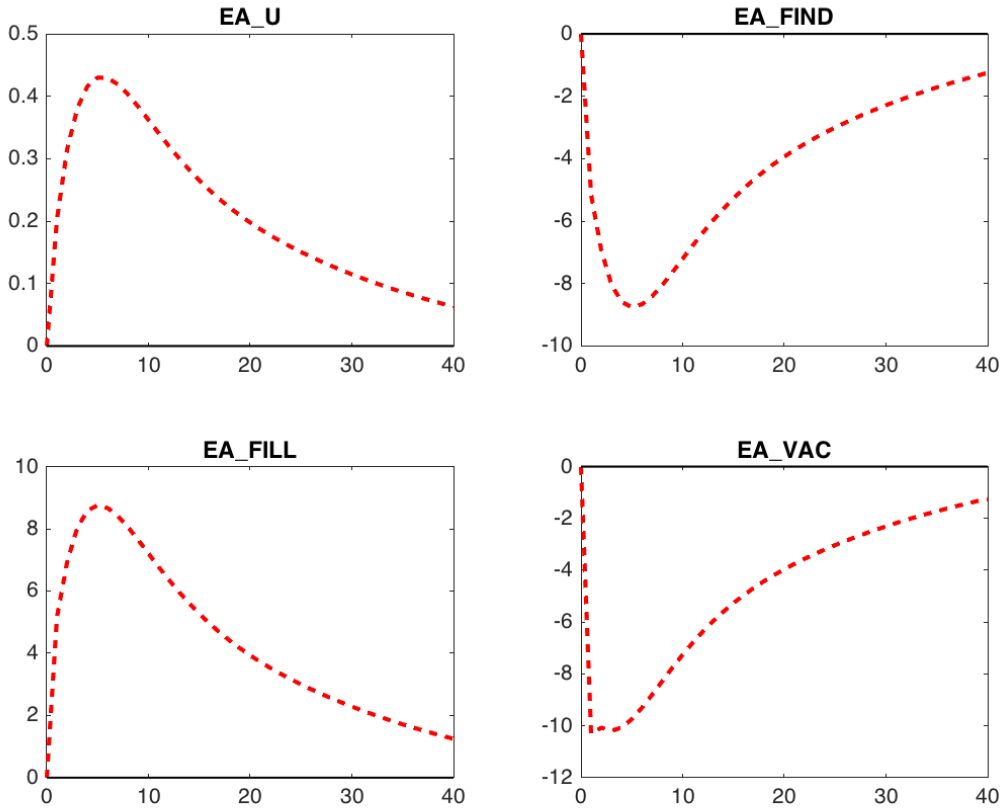


Graph 3.11. **Risk premium shock** (2)



Labour decreases more in the search and matching extension than in the baseline QUEST version. Taking a closer look at the Search & Matching extension, the hike in in investment risk premiums is accompanied by a cut in posted vacancies, increasing unemployment, increased filling rate and lower job finding rate.

Graph 3.12. **Risk premium shock** (3)



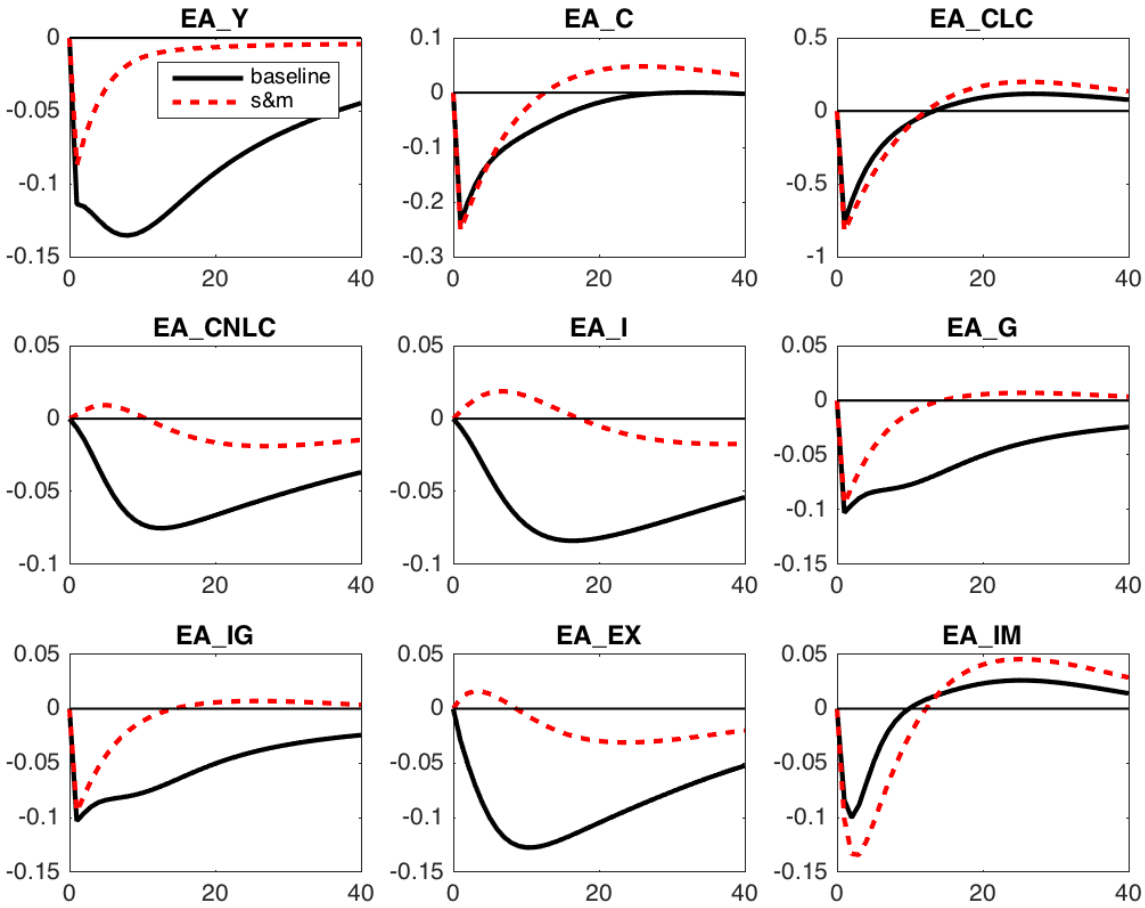
3.6 INCOME TAX SHOCK

With an income tax rate shock, we pass to taking a closer look at various shocks related to the labour market. A hike in this tax leads in both the baseline version of QUEST and its Search & Matching extension to a fall in output and lower employment. However, these effects are much more benign in the latter model. In the baseline model, higher income taxes directly influence the willingness to work by households, decreasing persistently labour supply. This forces firms to increase wages; prices increase causing second-round demand effects. As a consequence, demand aggregates (particularly, private consumption and investment) fall.

In contrast, a hike in labour tax does not have nearly as substantial effect on labour supply in the Search & Matching extension. In the latter model workers receive a strictly positive surplus from working, implying that unemployment is truly involuntary: the unemployed would be strictly better off working. A higher income tax, therefore, does not provoke a marginal adjustment: it only shrinks the

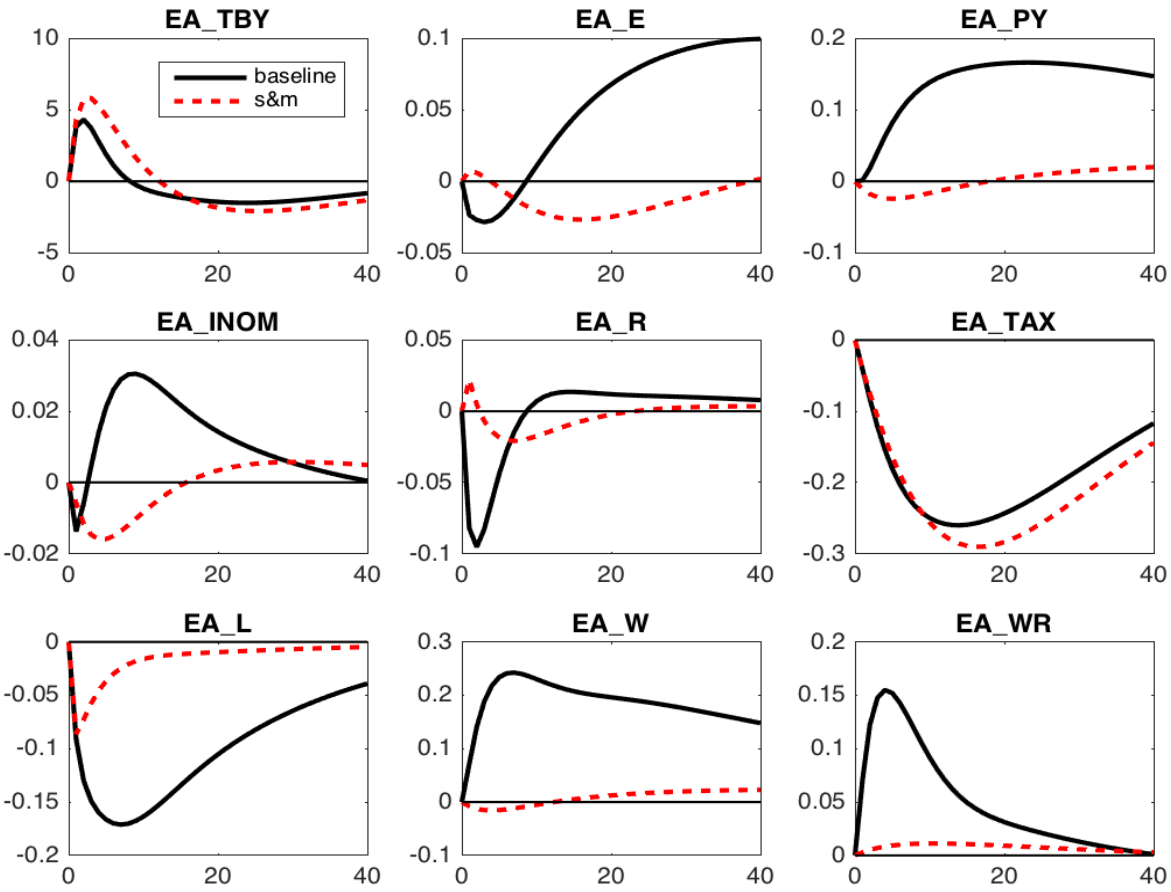
size of the pie shared between households and firms.[7] Firms, facing more expensive labour, simply switch to more capital-extensive production. This initially even leads to a moderate increase in consumption and investment of Ricardians (due to higher dividends; non-Ricardians suffer lower consumption as their disposable income shrinks). In effect, the recession in the latter model is relatively short-lived and has a less deep trough.

Graph 3.13. **Positive income tax rate shock** (1)



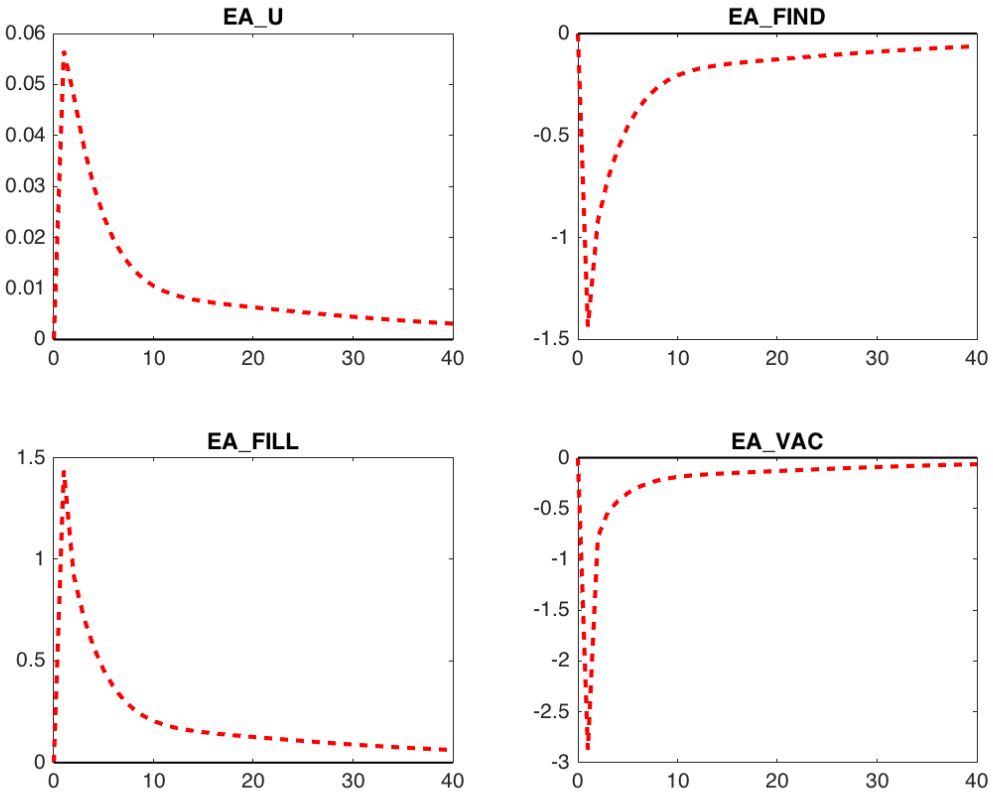
[7] In contrast, in the baseline model, households are exactly indifferent at the margin between work and leisure. Therefore, any change in the real wage rate (net of tax) induces them to change their labour supply.

Graph 3.14. **Positive income tax rate shock** (2)



In the Search & Matching version of the model, the hike in income tax is accompanied by increased unemployment, lower number of vacancies, a higher job filling rate and a lower job finding rate.

Graph 3.15. **Positive income tax rate shock** (3)

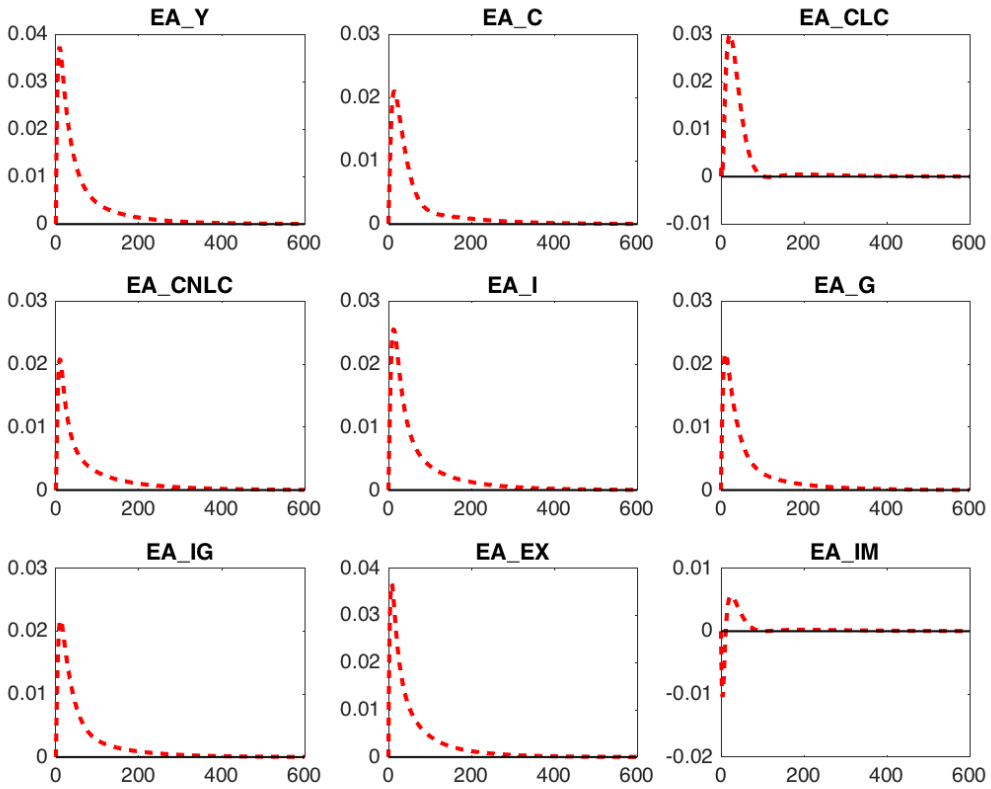


3.7 JOB FINDING RATE SHOCK

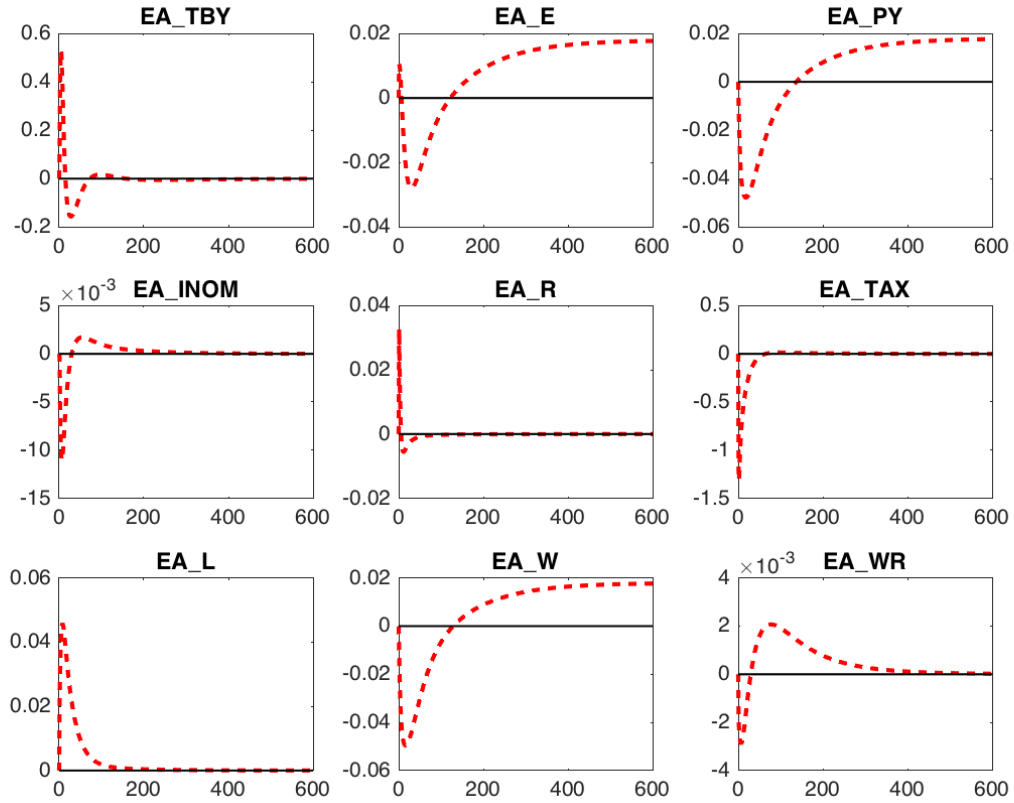
The next 4 shocks are confined to the Search & Matching extension of QUEST, since they do not have their counterpart in the baseline version of QUEST. We start with a shock which exogenously increases the job finding rate (EA_FIND)[8]. The higher rate at which the unemployed find employment is univocally favourable for the economy: output, as well as other demand aggregates (private consumption and investment as well as government spending) and employment increase (Graphs 3.16-3.18). This is due do to the fact that unemployed workers find jobs at a higher rate and thus get matched with vacancies more often. As a result, the real wage rate that a worker can expect to obtain in the bargaining process increases, but only in the medium-long run, due to the fact that the real wage rate in the current period is only affected by the finding rate in the next period (as can be seen in the equation of the real wage. This is why we have depicted long run effects in the graphs of this shock). Moreover, due to falling prices the real exchange rate decreases, improving the nation's trade balance. To understand these effects, it is worth noting that higher job finding rate lets firms cut the vacancies posted (Graph 3.18) since they no longer need to post as many vacancies as before to get a certain number of the latter filled. This decreases the cost of filling in a vacancy, which lets firms increase investment or pass savings to the households boosting demand as a second-round effect. Consequently, unemployment considerably decreases.

[8] This is equivalent to increasing the matching efficiency σ_m in equation (1).

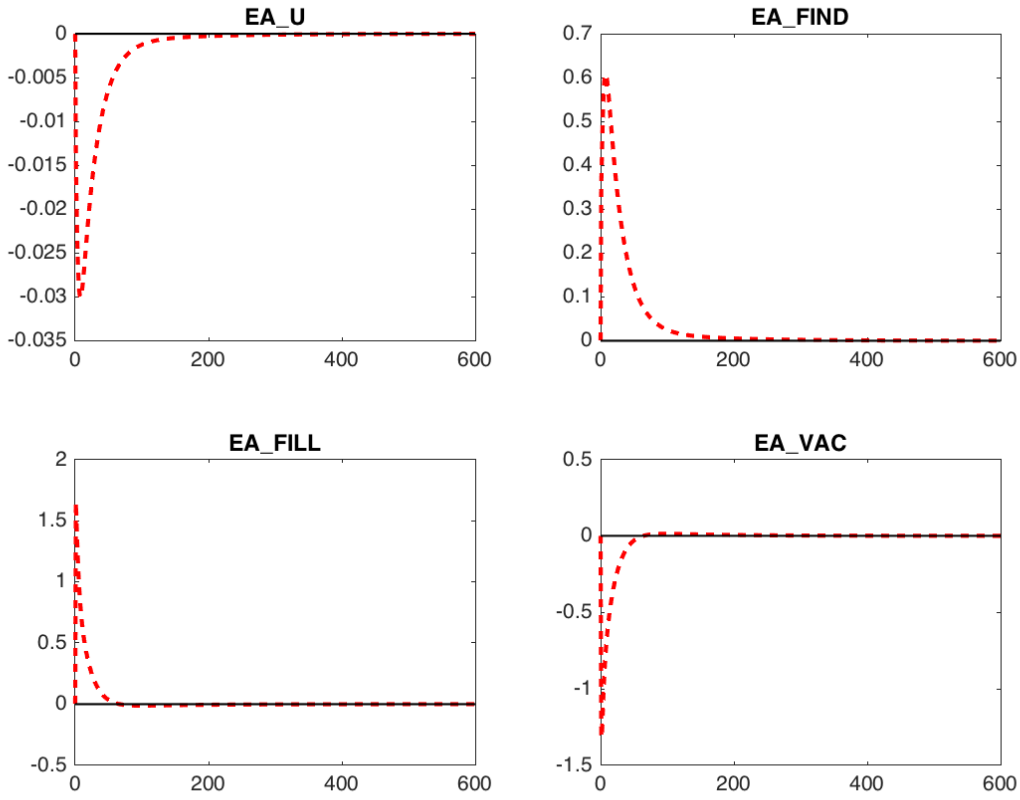
Graph 3.16. **Positive job finding rate shock** (1)



Graph 3.17. **Positive job finding rate shock** (2)



Graph 3.18. **Positive job finding rate shock** (3)

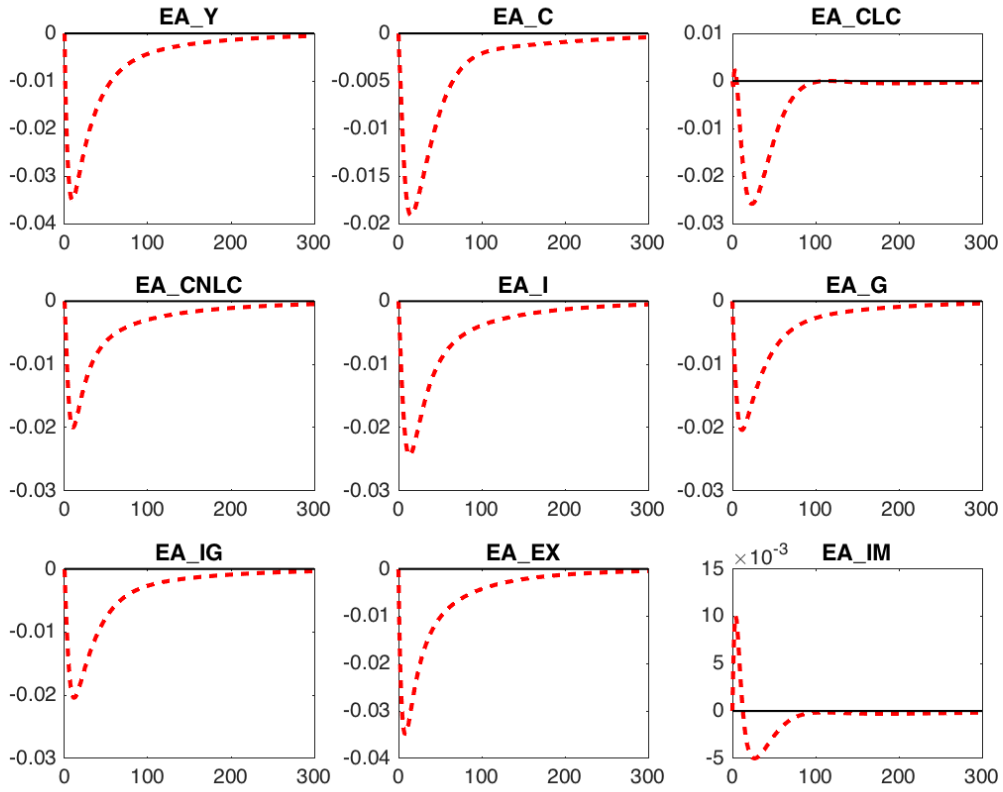


3.8 JOB SEPARATION RATE SHOCK

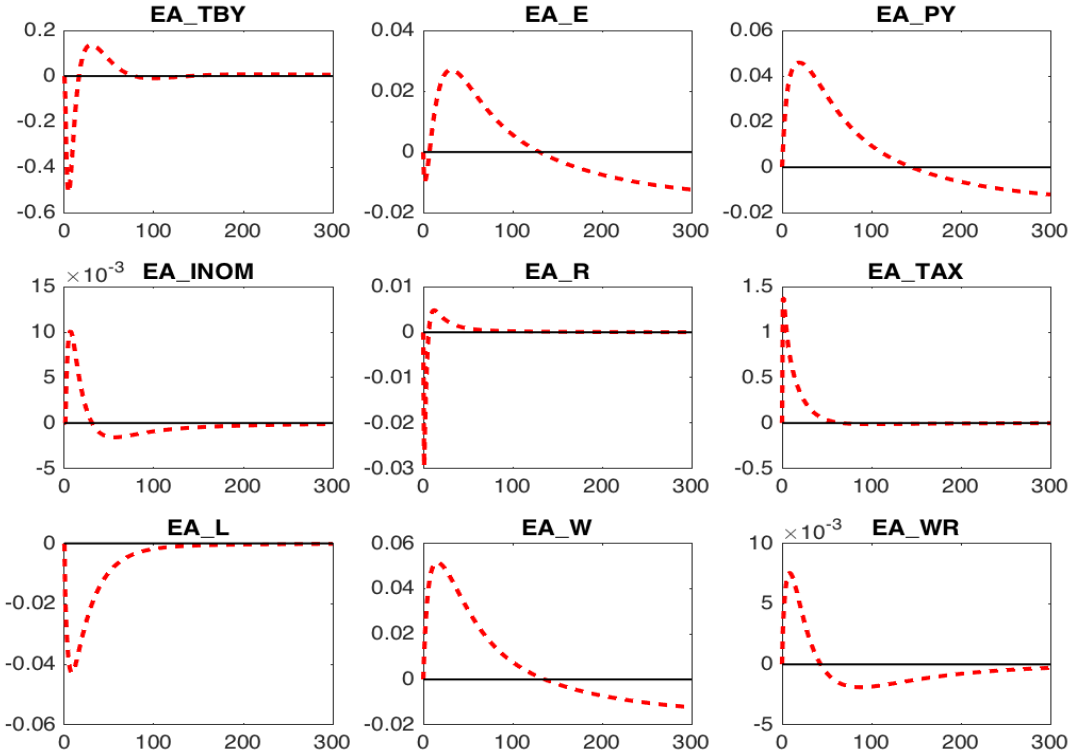
The macroeconomic effects of an increased rate at which workers and firms separate mirror the effects of a positive job finding rate, but with an opposite sign. Since the former shock makes production costlier, output and other demand aggregates as well as employment falls and current account deteriorates (Graphs 3.19-3.21). The fact that a higher separation rate is not equivalent to a lower job finding rate can be seen, however, by looking at the labour market specific variables. To make up for a higher separation rate, firms increase the number of vacancies posted to the extent that the job filling rate actually increases in the long run.[9] However, this effort is not enough to fully make up for the extra high speed of worker loss: despite the improved job filling rate, unemployment increases. The intuition is that for a same number of unemployed there are now less vacancies available, which increases the rate at which these vacancies get filled. As a consequence, some unemployed workers will not be able to find a vacancy and remain in unemployment, which explains why unemployment rises. The upshot is a fall in output, a rise in prices and a decrease in long run nominal wages which make real wages decrease in the long run. In the short run, real wages increase but not enough to counterbalance private consumption and investment. Due to less aggregate production, public spending also decreases.

[9] In contrast, a lower job finding rate would lead to a fall in the filling rate, see Graph 3.18.

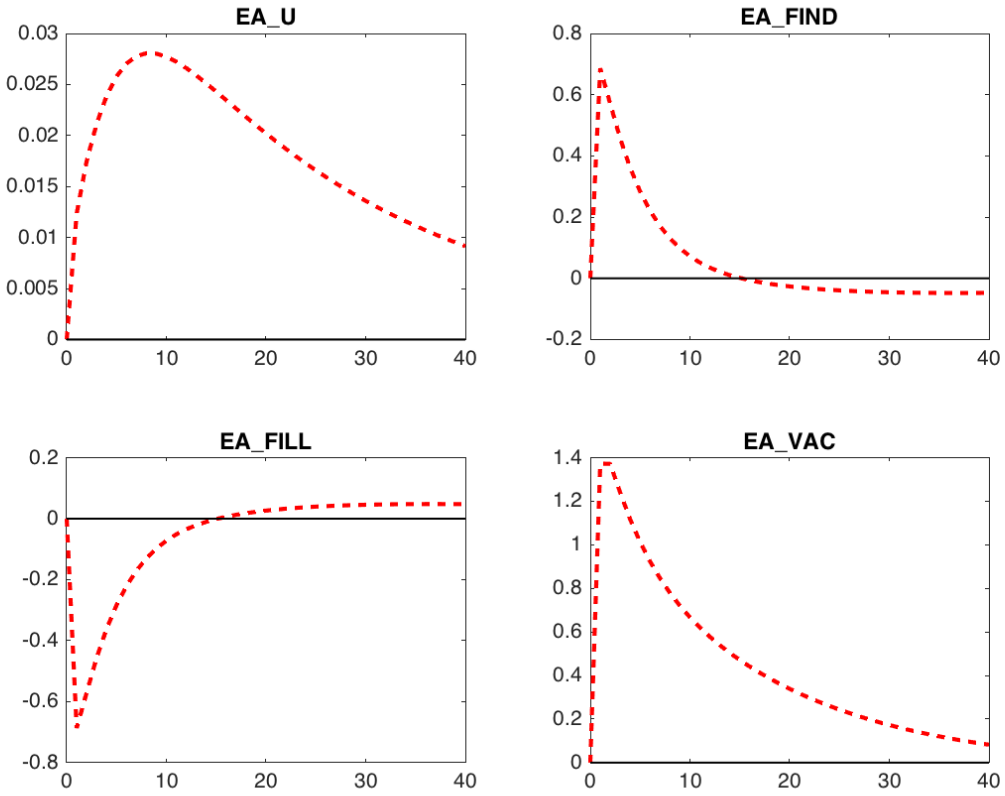
Graph 3.19. **Job separation rate shock** (1)



Graph 3.20. **Job separation rate shock** (2)



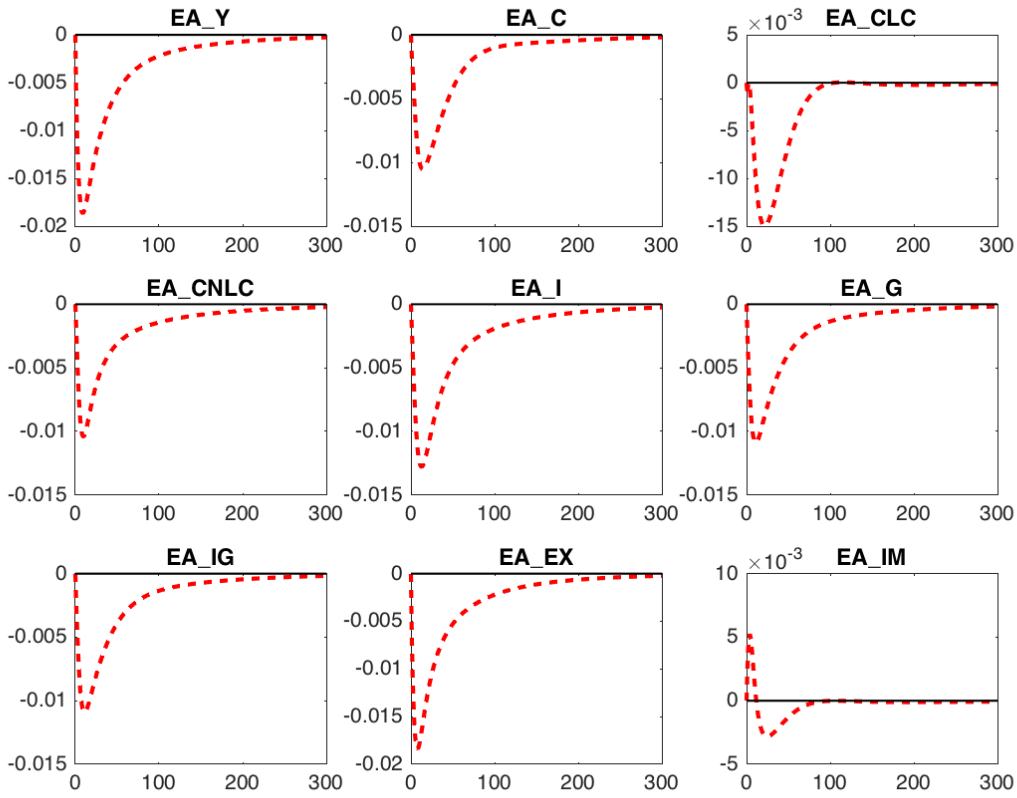
Graph 3.21. **Job separation rate shock** (3)



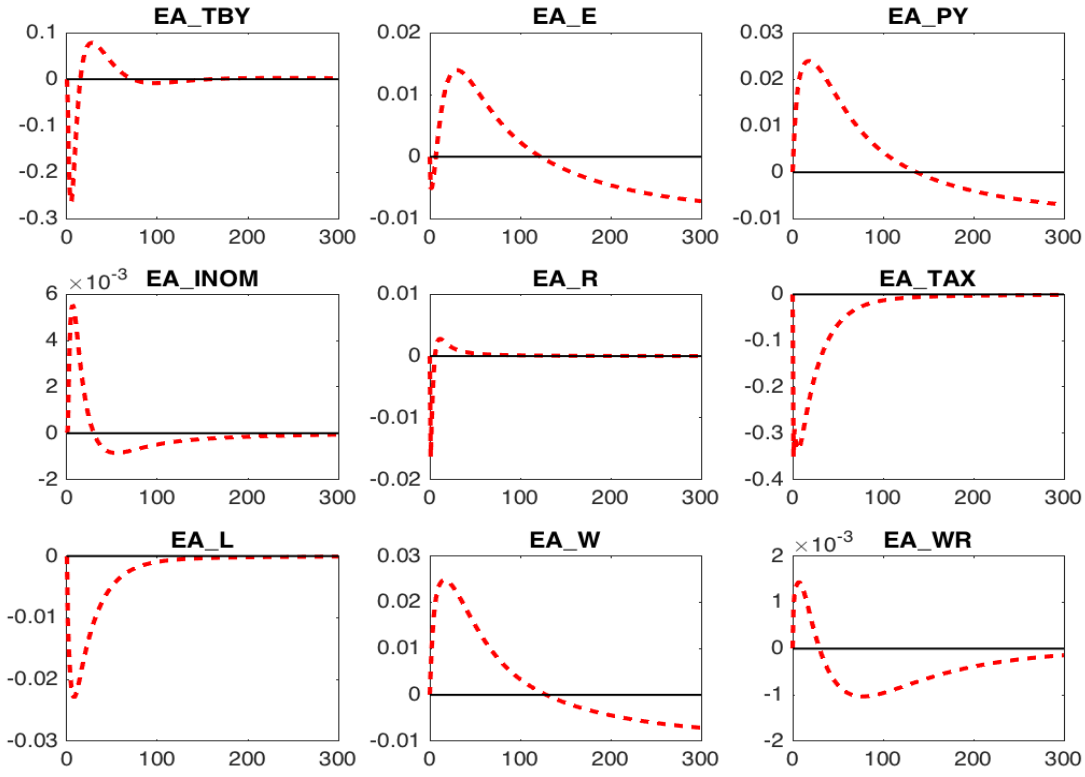
3.9 VACANCY COST SHOCK

A shock to the cost of a posted vacancy is another shock which has clear-cut macroeconomic consequences. Similar to an increased job separation rate, higher vacancy costs reduce production efficiency, leading to lower output and other demand aggregates as well as employment and to deterioration of the current account (Graphs 3.22-3.24). Firms decrease the number of vacancies which increases the job filling rate. At the same time, unemployment increases which makes the finding rate decrease.

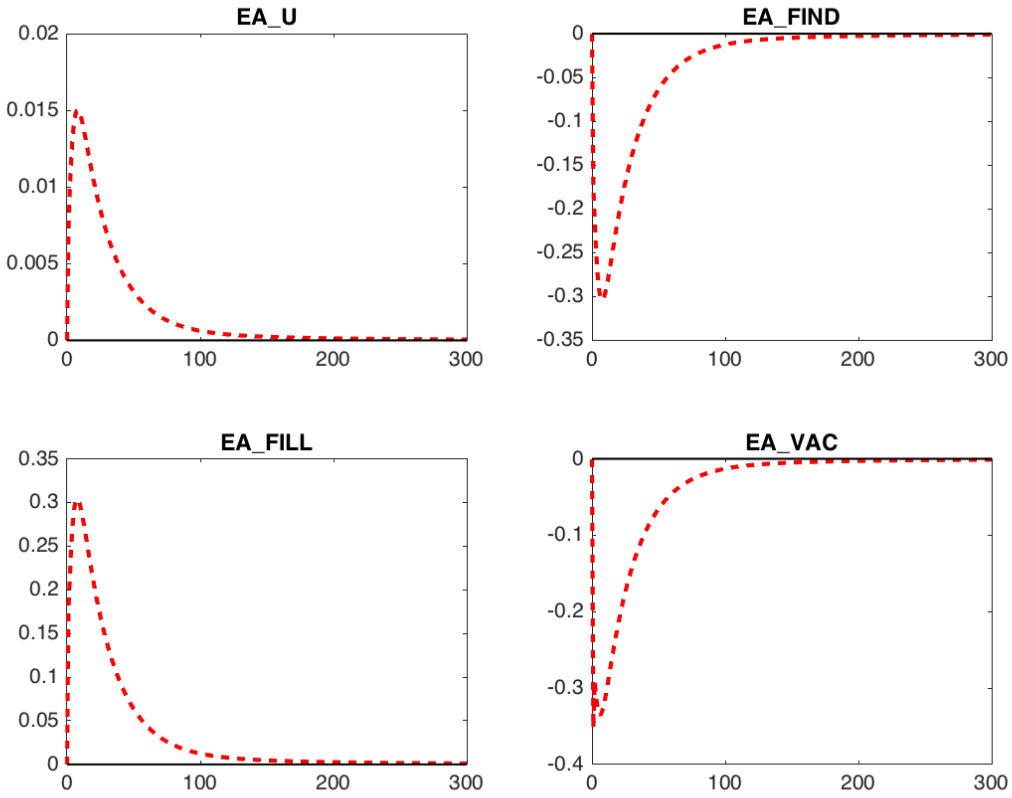
Graph 3.22. **Positive vacancy cost shock** (1)



Graph 3.23. **Positive vacancy cost shock** (2)



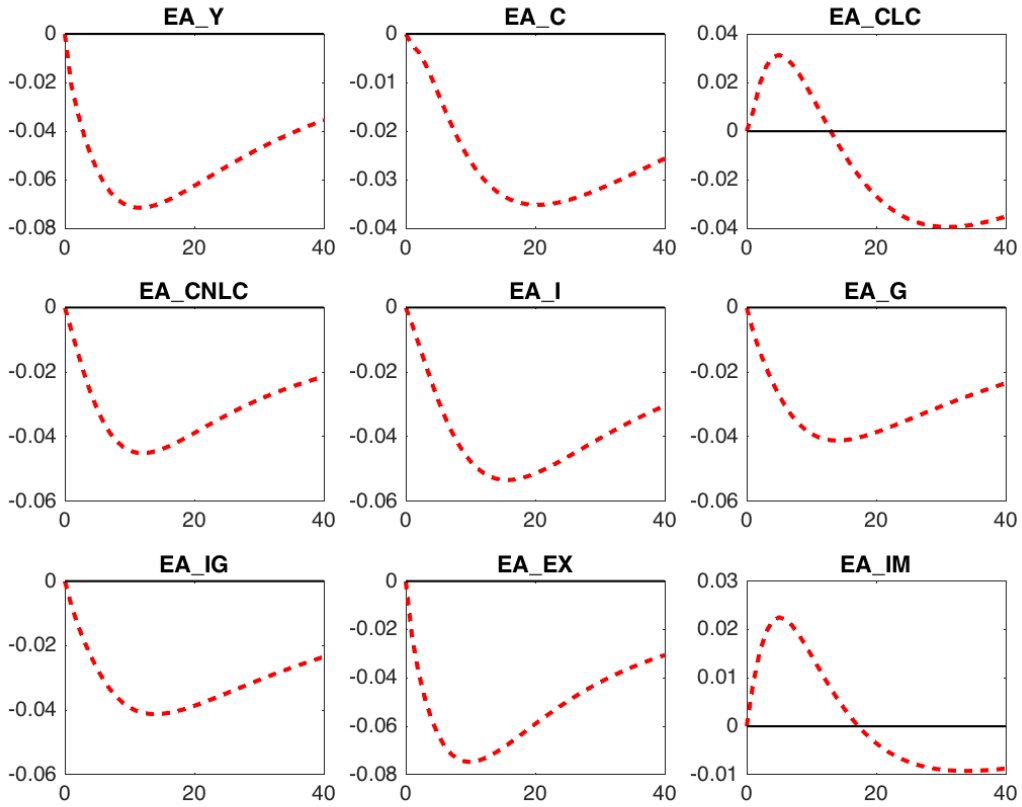
Graph 3.24. **Positive vacancy cost shock** (3)



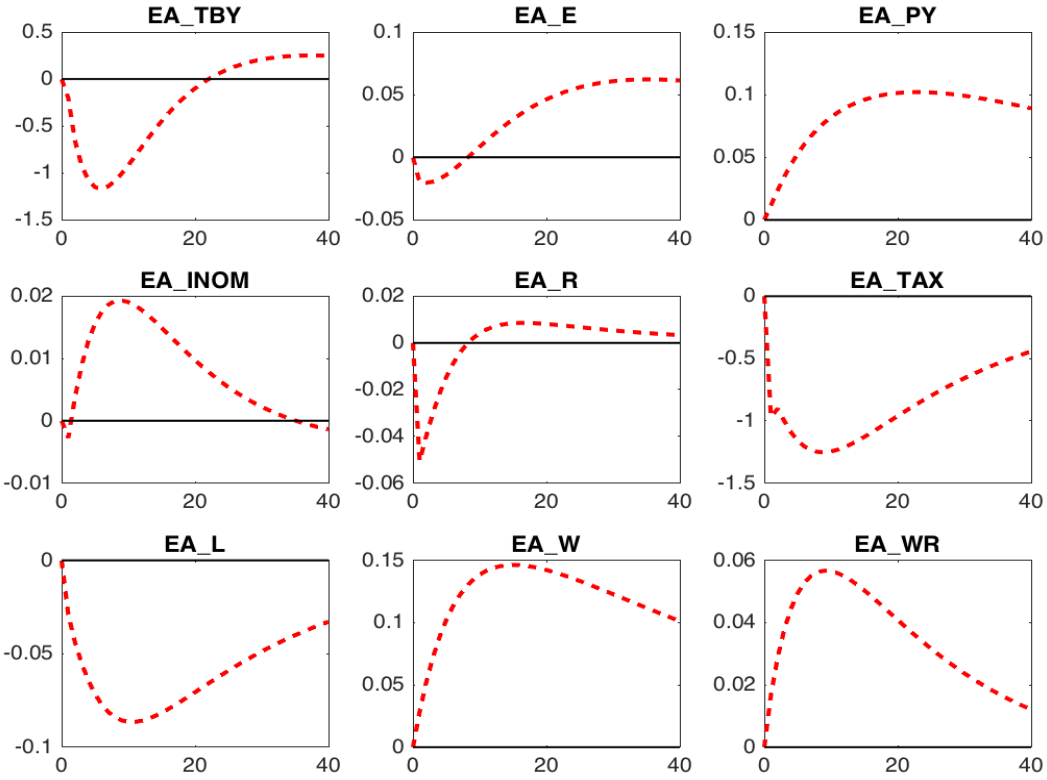
3.10 WORKER'S BARGAINING POWER SHOCK

Increasing workers' bargaining power raises their negotiation power and as a result, real wages (see Graph 3.26). The upshot of this is the cost of employing workers for firms increasing, thus making the production process costlier and total output decreases. As firms expected profits from a filled vacancy decrease, their reaction is to cut vacancies (Graph 3.27), leading to an increase in unemployment, a rise in the filling rate and a decrease in the job finding rate. The increase in real wages also lowers output by reducing the demand for labour. Although, all things being equal, an increase in real wages has positive implications for private consumption and investment, this effect is outweighed by the fall in demand for labour, which reduces both consumption and investment. As a result, government consumption and investment are crowded out and the trade balance decreases (exports decrease and imports increase).

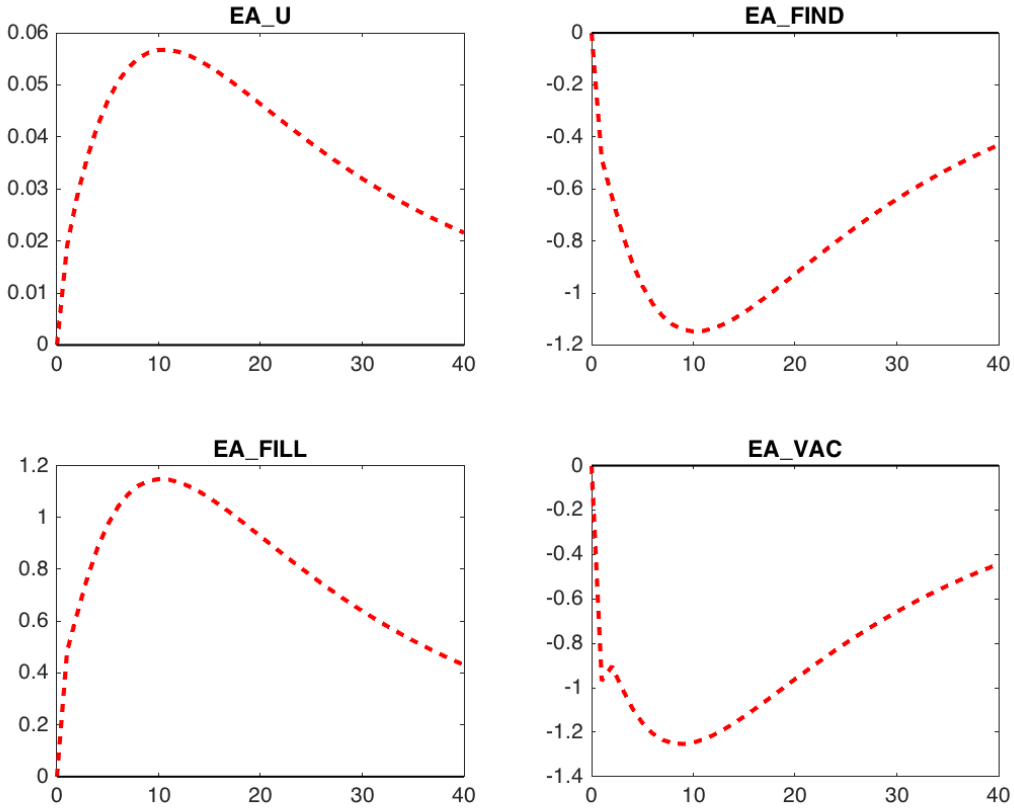
Graph 3.25. **Positive worker's bargaining power shock** (1)



Graph 3.26. **Positive worker's bargaining power shock** (2)



Graph 3.27. **Positive worker's bargaining power shock** (3)



4. CONCLUSION

In this paper, we have documented a search & matching extension of the basic version of QUEST model. The simulations carried out with the extended model show that, both qualitatively and quantitatively, both models imply similar dynamics of common variables in reaction to exogenous shocks. However, the extended model provides the means for a much deeper analysis of employment stocks and flows in and out of unemployment. As such, it is hoped to become a useful tool for policy work on labour market and labour market policies.

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