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Incorporating Labour Market Frictions into an Optimising-Based Monetary Policy Model*

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Abstract

This paper examines the effects of introducing a non walrasian labour market into the "New Neoclassical Synthesis" framework. A dynamic stochastic general equilibrium model is formulated, solved and calibrated to evaluate its abilities to replicate the main features of the Euro area economy. This framework allows the respective roles of labour market rigidities, nominal rigidities, and policy inertia in accounting for the impact of monetary policy, technology, public spending and preference shocks to be studied. Our simulations show that: (i) real rigidities complement but not supplant nominal rigidities, (ii) the Beveridge and Phillips relations are reproduced, (iii) hours worked are a *too crucial* adjustment variable and (iv) the real wage dynamics is still procyclical.

Keywords : DSGE models, nominal rigidities, real rigidities, labour market search, endogenous persistence, Euro area.

JEL Classifications : E52, C52, E24

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By placing amplification and persistence mechanisms in formal general equilibrium models, contributors to modern fluctuations research achieve a degree of clarity missing from earlier macroeconomics. Without consideration of unemployment, models explained persistence in employment largely through persistence in driving forces. Where unemployment is considered explicitly, persistence arises naturally from the time-consuming process of placing unemployed workers in jobs following an adverse impulse.

Robert E. Hall (1999)

1 Introduction

The consequences of labour market frictions on employment, output and inflation constitute an issue of great importance for both economists and policymakers. As explained in a recent work on labour market mismatchs provided by the European Central Bank (ECB, 2002), there is a gap between the European unemployment level and the difficulties in recruiting workers. This coexistence of unsatisfied labour supply and demand suggests an insufficient ability of the Euro area to match labour supply and demand. Moreover, it is generally agreed that the unemployment in Euro area is only to a small extend cyclical and that the major part of it is institutional and structural. Unfortunately, these European characteristics, like the low mobility of the manpower across countries and the high level of regulation, create a rigid labour market configuration (Bertola (1999), Cadiou and Guichard (1999) and Cadiou *et al.* (1999)).[1]

The persistently high rate of unemployment (8.6%), the low level of participation (68,6%) and the uneven labour market performance accross Euro area countries indicate that these intrinsic frictions cannot be neglected and that the understanding of labour market matching processes is of considerable importance for monetary policy. Indeed, bottlenecks in the labour market may trigger inflationary pressures and differences in the labour market functioning and the impossibility to use country-specific monetary and exchange rate policies leads asymmetrical effects following a symetric or asymetric shock. Consequently, less friction on labour market of Euro area should reduce the short-run effects of monetary policy on the real economy. It

[1] The two main instruments of regulation are: (i) employment-protection legislation which makes it costly or difficult for employers terminate jobs without cause, and (ii) institutional features of rigid European labor markets which limit the extend to which wages may fluctuate over time and differ across workers performing similar duties.

is no longer possible to circumvent the modelling of the labour market frictions in a macroeconomic model on which the economists base their policy recommendations.

Since the effects of labour market frictions impinge on all aspects of the economy, it is necessary to apprehend their role in the context of a perfectly integrated economy-wide model. Until now, there has been a sparse literature evaluating the role of labour market. On the one hand, several papers have considered labour market search in real business cycles (RBC) models (Merz (1995), Andolfatto (1996), den Haan, Ramey and Watson (2000)). It has been shown to generate realistic dynamics in US employment and to increase, for example, the magnitude and persistence of the impact of productivity shocks on ouptut. However, these models are not really adapted to monetary policy analysis. On the other hand, other authors have introduced staggered-nominal wage contracts into the new generation of small-scale monetary business models called "New Neoclassical Synthesis" models (see, *inter alia*, Huang and Liu (1998), Erceg, Henderson and Levin (2000), Edge (2002), Amato and Laubach (2003)).[2] The main motivation is to generate more persistence in output and inflation following a shock. In this context, Christiano, Eichenbaum and Evans's (2001) paper is a perfect synthesis of these latest developments allowing to characterise the observed inertial behavior of inflation and persistence in aggregate quantities.[3] While these models are successful at explaining a number of phenomena, their lack of implications about the unemployment rate is a drawback.

This paper is intended as a step in addressing the evaluation of labour market frictions. In particular, it is interested in quantitatively studying the effects of introducing a dynamic labour market that incorporate job search into a dynamic stochastic general equilibrium (DSGE) model. Indeed, we think that the matching model may provide a simple and elegant representation of European labour market characteristics in capturing the salient features of the theory of unemployment. Our labour market specification is then based on theoretical search models of the labour market in the spirit of Blanchard and Diamond (1989). The basic incentive for search activities in the labour market by both workers and firms are the profit opportunities in present value terms which are associated with a successful job match for both parties. Wages are determined by an implicit bargain at the individual level, i.e. the firm engages in Nash bargains with each individual worker by taking the wage of all other employees

[2]See the seminal papers of Goodfriend and King (1997), Clarida et *al.* (1999) or Woodford (2002) for a presentation of the New Neoclassical Synthesis framework.

[3]Smets and Wouters (2002) apply and estimate such a model for the Euro area. Kortelainen (2001) also builds a Euro area macroeconomic model with some nominal rigidities although quite far from the actual DSGE models features.

as given. Thus, wage contracts are set so as to maximise the product of their respective profit opportunities. In this setup, the labour market is non-Walrasian involving real rigidity in the line of Ball and Romer (1990) or Jeanne's (1998) recommandations (nominal rigidities need to be supplemented by real rigidities).[4]

To the best of our knowledge, there are two other (independent) attempts that have introduced labour market search into the "New Neoclassical Synthesis" framework. Walsh (2002) incorporates a labour market matching process together with price stickiness in a cash-in-advance model and studies the implications for the persistent output effects of monetary policy shocks. Trigari (2002) extends work of the first while being interested either in the extensive margin but also intensive and while seeking to explain a set of facts regarding job flows, unemployment and inflation dynamics. Both find that labour market search helps to explain the sluggishness of inflation and the persistence of output after monetary policy shocks. However, their modelling suffers from not taking into account the capital factor in the production function. Firstly, adjustment costs for capital and their interaction with the labour market frictions affect firms' hiring. And secondly, allowing for labour market search to interact with capital adjustment costs improves the performance of investment dynamics and so output ones (Chéron and Langot (1999) and Merz and Yashiv (2002)). We can also notice that their analysis focus only on monetary policy shocks and occult other crucial shocks like technology or government spending ones.

The paper is organised as follows. Section 2 is devoted to the presentation of the monetary general equilibrium model. In section 3 the model is calibrated for the Euro area economy using Euro area data and standard parameters from applied general equilibrium studies. We explore the descriptive power of the simulated data and perform some simulations. Finally section 4 conludes and gives directions for future research.

2 The Model Economy

We consider a dynamic stochastic general equilibrium model along the lines of Christiano, Eichenbaum and Evans (2001), Neiss and Nelson (2001), and others. Our specification mainly departs with respect to two assumptions. First, to incorporate physical capital and investment in a "realistic" manner, we base the investment analysis on the Q theory which implies that in a firm's investment optimum, the firm

[4] Although his model provided no underlying theory to explain the labor market rigidity, Jeanne pointed that *"[...] While different types of real rigidity may be considered, we would argue that there are several reasons to consider those arising in the labor market first"* (p.1028).

optimally weights current marginal costs of investment against the future marginal returns.[5] Second, following Blanchard and Diamond (1989) and Pissarides (2000), we use the economics of search that allows us to study the implications of labour market frictions for economic behavior and market performance.

The economy consists of a government and numerous agents of three different types: households, wholesalers and retailers. Households choose consumption, leisure and real-balances to maximise the present value of utility streams. It is assumed that there is an insurance market in the economy such that agents can insure themselves fully against idiosyncratic risks. This assumption makes households ex-ante identical and simplifies the analysis (see Appendix A). The government consumes a share of final good and conducts fiscal and monetary policy by using the nominal interest rate as its instrument. Production of final goods takes place in two stages. Perfectly competitive wholesalers manage the production of the same homogeneous imput good and make investment and hiring decisions. Finally monopolistically retailers buy the input good to produce differenciated final goods sold with the households and set prices according to the discrete-time version of Calvo's (1983) model.

2.1 Households

The economy is populated by a representative household constituted by a continuum of members indexed on the unit interval. He has preferences defined over a composite consumption good (C_t), employment's rate (N_t), hours worked (H_t), and real money balances (Ξ_t/P_t). Money enters the utility function directly to capture the idea that real balances provide a transactions-facilitating service. The representative household chooses a sequence of consumption (C_t), nominal money (Ξ_t) and one-period bond (B_{t+1}), to maximise his lifetime utility:

$$E_t \sum_{i=0}^{\infty} \beta^i \varepsilon_t^p \left[u\left(C_{t+i}, C_{t+i-1}\right) - N_{t+i} l\left(H_{t+i}\right) + v\left(\frac{\Xi_{t+i}}{P_{t+i}}\right) \right] \tag{1}$$

where $\beta \in (0,1)$, ε_t^p, $u\left(C_{t+i}, C_{t+i-1}\right)$, $l\left(H_{t+i}\right)$ and $v\left(\frac{\Xi_{t+i}}{P_{t+i}}\right)$ represent respectively the discount factor, a general shock to preferences that affects the intertemporal substitution of households (asssumed to follow a first-order autoregressive process with i.i.d. Normal error term: $\ln(\varepsilon_t^p) = \left(1-\rho_p\right) \ln\left(\bar{\varepsilon}^p\right) + \rho_p \ln(\varepsilon_{t-1}^p) + e_{1,t})$, the instantaneous consumption utility, the instantaneous work disutility and the the utility associated

[5] Authors generally make the nonrealistic but simplifying assumption that in fact the households make the capital accumulation and utilisation decisons.

to real cash balances; they are given by:

$$u\left(C_t, C_{t-1}\right) = \frac{\sigma_c}{\sigma_c - 1}\left(\frac{C_t}{C_{t-1}^h}\right)^{\frac{\sigma_c - 1}{\sigma_c}}, \tag{2}$$

$$l\left(H_t\right) = \frac{\sigma_n}{\sigma_n + 1}\left(H_t\right)^{\frac{\sigma_n + 1}{\sigma_n}} \tag{3}$$

and

$$v\left(\frac{\Xi_t}{P_t}\right) = \frac{\sigma_m}{\sigma_m - 1}\left(\frac{\Xi_t}{P_t}\right)^{\frac{\sigma_m - 1}{\sigma_m}} \tag{4}$$

σ_c is the intertemporal elasticity of substitution of consumption, σ_n is the elasticity of labour desutility with respect to hours worked, σ_m represents the elasticity of money holdings with respect to the interest rate. Preferences over consumption take on a non time separable form capturing the idea that households may exhibit habit formation in their consumption patterns. The parameter $h \in [0, 1]$ represents the habit formation parameter which measures the effect of habit stock (proportional to last consumption) on current utility. We work with strictly positive h in this paper in light of evidence that doing so reduces some of the empirical shortcomings of quantitative business cycle models (Boldrin, Christiano and Fisher (1999), or Fuhrer (2000)).[6]

The representative household respects at each period the intertemporal budget constraint:

$$C_t + \frac{\Xi_t}{P_t} + \frac{B_{t+1}}{\left(1 + i_t\right) P_t} \leq W_t N_t H_t + \frac{B_t}{P_t} + \frac{\Xi_{t-1}}{P_t} - T_t + \Pi_t^r + \Pi_t^w \tag{5}$$

where W_t is the hourly real wage, i_t denotes the nominal interest rate, T_t denotes the real lump-sum tax (government transfers) and Π_t^r and Π_t^w are respectively the dividends derived from retailers and wholesalers.

The composite consumption good C_t is a Dixit-Stiglitz aggregate of a multiplicity of differentiated goods indexed by $z \in [0, 1]$. As usual, the composite consumption good and price index are then defined as:

$$C_t = \left[\int_0^1 C_t\left(z\right)^{\frac{\epsilon - 1}{\epsilon}} dz\right]^{\frac{\epsilon}{\epsilon - 1}} \tag{6}$$

[6] Fuhrer (2000) showed that habit formation allows the model to match the response of real spending to monetary-policy shocks. It is a real motivation for using habit formation as an a priori desirable modification to the standard model.

$$P_t = \left[\int_0^1 P_t(z)^{1-\epsilon} dz \right]^{\frac{1}{1-\epsilon}} \quad (7)$$

which can be derived from two-stage budgeting. The parameter $\epsilon > 1$ is the elasticity of substitution between differentiated retail goods or equivalently the price elasticity of demand.

Noting λ_t as the Lagrange multiplier on (5), optimal household behavior yields the following first-order conditions:

$$(C_t) \qquad \varepsilon_t^p \left(\frac{C_t}{C_{t-1}^h} \right)^{\frac{\sigma_c - 1}{\sigma_c}} \frac{1}{C_t} - \beta h E_t \left\{ \varepsilon_{t+1}^p \left(\frac{C_{t+1}}{C_t^h} \right)^{\frac{\sigma_c - 1}{\sigma_c}} \frac{1}{C_t} \right\} = \lambda_t \quad (8)$$

$$(M_t) \qquad \varepsilon_t^p \left(\frac{\Xi_t}{P_t} \right)^{-\frac{1}{\sigma_m}} = \lambda_t - \beta E_t \frac{\lambda_{t+1} P_t}{P_{t+1}} \quad (9)$$

$$(B_{t+1}) \qquad 0 = \lambda_t - (1 + i_t) \beta E_t \frac{\lambda_{t+1} P_t}{P_{t+1}} \quad (10)$$

Equation (8) combinated with (10) gives a modified Euler equation. Equation (9) is the dynamic condition for the choice of money holdings. The marginal cost of foregoing one unit of consumption today must be equal to the pecuniary benefit of being able to buy an extra unit of consumption tomorrow, plus the pecuniary benefit measured by the current utility flow of an extra unit of money. However, we will be unaware of this money demand equation because money plays no role in this model.[7]

2.2 Labour Market Matching

The labour market specification is based on theoretical search models of labour market as well documented by Pissarides (2000).

At the macroeconomic level, the law of motion of agregate employment (N_t) is

$$N_{t+1} = (1 - s)N_t + M_t \quad (11)$$

where $s \in [0, 1]$ is a given exogeneous job separation rate, constant over time, that ensures that a proportion s of all filled jobs disappears at each instant, and M_t is the number of recrutings at period t. Thus, matchings which take place at the period t are only productive at the following period.

[7] The monetary authority uses the nominal risk free interest rate as monetary policy tool, and lets the amount of nominal money adjust accordingly, for a given price level.

The matching function is a very convenient hypothetical concept whose basic idea is that the recruiting effort of employers and the search effort of workers serve as inputs in a market matching function that generates new hires.[8] The job vacancies (V_t) and unemployed agents ($U_t = 1 - N_t$) are randomly matched with each other. The aggregate flow of job matches are deterministic and given by the following matching technology:

$$M_t = M(U_t, V_t) = \tilde{m} U_t^{\alpha} V_t^{1-\alpha} \tag{12}$$

where $\alpha \in (0, 1)$ and $\tilde{m} > 0$ is a scale parameter. The matching technology exhibits constant return-to-scale and we choose a Cobb-Douglas form for its simplicity.

At each moment in time, the job vacancies and unemployed workers that are matched are randomly selected from the sets V_t and U_t. Hence, the process that changes the state of vacant jobs during an interval of time is Poisson with rate

$$\tau_t = \frac{M(U_t, V_t)}{V_t}$$

In other words, τ_t can be interpreted as the instantaneous probability of a vacancy being filled, and the average expected duration of a job vacancy is $\frac{1}{\tau_t}$.

Similarly, the instantaneous probability of an unemployed worker finding a job is given by:

$$\varrho_t = \frac{M(U_t, V_t)}{U_t} \tag{13}$$

which means that the average expected duration of unemployment is $\frac{1}{\varrho_t}$.

The definitions of τ_t and ϱ_t show that there is an intricate connection between the process linking workers to jobs, and the one linking jobs to workers. This is obvious, since workers and vacancies meets in pairs. For this reason, we generally look at a simple measure of labour market tightness, the vacancy-unemployment ratio $\left(\text{or equivalently } \theta_t = \frac{\varrho_t}{\tau_t}\right)$, since it plays a crucial role in the labour market analysis. Indeed, the dependance of the search probabilities on θ implies the existence of a trading externality. There is stochastic rationing occuring in the labour market which cannot be solved by the price mechanism, since worker and vacancy must first get together before the price mechanism can play any role.

[8] Firms have jobs that are filled or vacant and workers have a job or are unemployed but only the vacant jobs are offered and unemployed person are engaged in search. This assumption implies that the two activities of production of goods and trade in labour market are strictly separate activities.

2.3 Wholesalers

We consider a representative firm which acts on a perfect competition market and make investment and hiring decisions. Each period, this firm uses physical capital (K_t) and labour (total hours, $N_t H_t$) as input in order to produce a homogeneous wholesale good (X_t^w) which cannot be consumed and will be sold to retailers at relative price $\Upsilon_t = \frac{P_t^W}{P_t}$ to produce a differenciated final good. Then the production technology is given by

$$X_t^w = f\left(\varkappa_t K_t, N_t H_t\right) = \varepsilon_t^a \left(\varkappa_t K_t\right)^\eta \left(N_t H_t\right)^{1-\eta} \tag{14}$$

where $\eta \in (0,1)$, $\varkappa_t$ is the utilisation rate and ε_t^a is an exogenous technology shock (assumed to follow a first-order autoregressive process with i.i.d. Normal error term: $\ln(\varepsilon_t^a) = (1-\rho_a)\ln\left(\bar{\varepsilon}^a\right) + \rho_a \ln(\varepsilon_{t-1}^a) + e_{2,t}$).

The neo-classical model of investment can be linked to Tobin's Q-model, which couples investment decisions to forward-looking stock market valuations of the firm.[9] According to this hypothesis, investment is determined by the gap between the market value of a firm and the replacement value of its capital. The ratio between the two variables is referred to as Tobin's Q. This model can be derived from the theory if it is assumed that investment is subject to adjustment costs, which are a convex function of the rate of change of the firm's capital stock. A necessary condition is convexity which implies that these installation costs increase at an increasing rate and a too rapid accumulation of capital is more costly.

The firm's stock of physical capital evolves according to:

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

where I_t denotes time t purchases of investment goods and $\delta\left(\varkappa_t\right)$ a positive, increasing and convex function of the utilisation rate defined by,

$$\delta\left(\varkappa_t\right) = \tilde{\delta}\frac{\varkappa_t^d}{d}$$

that reflects the fact that a higher utilisation rate raises the depreciation rate on capital, or equivalently that equipment and machinery are used more intensively in booms than in recessions (King and Rebelo (1999)). $\tilde{\delta} > 0$ is a scale parameter.

The functionnal form chosen here for the adjustment costs is given by:

$$A\left(I_t, K_t, \varkappa_t\right) = \frac{\Theta}{2}\left(\frac{I_t}{K_t} - \delta\left(\varkappa_t\right)\right)^2 K_t \tag{15}$$

[9] See Gertler and Gilchrist (2000) for a look at the macroeconomic consequences of investment delays in a staggered-prices framework.

with $\Theta > 0$.

The real profit of the wholesale goods producer is defined as the difference between the revenue from the sale of output and total labour compensation, the cost of hiring labour (the cost of posting vacancies expressed in terms of consumption (ς)), and investment plus adjusment costs:

$$\Pi_t^w = \Upsilon_t f\left(\varkappa_t K_t, N_t H_t\right) - W_t N_t H_t - \varsigma V_t - \left(I_t + A\left(I_t, K_t, \varkappa_t\right)\right) \tag{16}$$

The problem of this firm is to choose the demand for labour, vacancies, the rate of investment, the value of capital and utilisation rate such as maximise the expected sum of discounted profits, taking as given the per vacancy cost, the evolution of employment and capital (which are predetermined) and the path of wages and hours worked (at this stage). It is defined as:

$$\max_{\{N_{t+1} V_t, K_{t+1}, I_t, \varkappa_t\}} E_t \sum_{j=o}^{\infty} \beta^j \frac{\lambda_{t+j}}{\lambda_t} \Pi_{t+j}^w \tag{17}$$

subject to the following constraints:

$$\begin{aligned} N_{t+1} &= (1-s) N_t + \tau_t V_t && (18) \\ K_{t+1} &= (1-\delta(\varkappa_t)) K_t + I_t && (19) \end{aligned}$$

The Lagrange multipliers associated with these two constraints are Q_t^N and Q_t^K, respectively. These Lagrange multipliers can be interpreted as Tobin's marginal Q for physical capital, and a Tobin's Q equivalent for employment.[10] The first-order conditions of this program are given by:

$$(N_{t+1}) \qquad Q_t^N = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\Upsilon_{t+1} f_{N_{t+1}}^{t+1} - W_{t+1} H_{t+1} + (1-s) Q_{t+1}^N \right) \right] \tag{20}$$

$$(V_t) \qquad Q_t^N = \frac{\varsigma}{\tau_t} \tag{21}$$

$$(K_{t+1}) \qquad Q_t^K = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\Upsilon_{t+1} f_{K_{t+1}}^{t+1} - A_{K_{t+1}}^{t+1} + (1-\delta) Q_{t+1}^K \right) \right] \tag{22}$$

$$(I_t) \qquad Q_t^K = 1 + A_{I_t}^t \tag{23}$$

[10] These representations of Q_t^N and Q_t^K allow us to interpret them as reflecting the present discounted value of the marginal revenu from current employment and investment and illustrate the forward looking nature of the law of motion of employment and capital accumulation.

$$(\varkappa_t) \qquad \Upsilon_t f^t_{\varkappa_t} = K_t \delta^t_{\varkappa_t} \tag{24}$$

Equation (20) defines the Tobin's Q for employment, Q_t^N, as the profit the new worker will make to the firm at $t+1$ plus the expected Tobin's Q which is 0 with probability s if the worker separates from the firm, and is Q_{t+1}^N if he remains to work in the following period. Equation (21) is a free-entry condition (it equates the recruiting cost of a vacancy to the expected present value of holding a vacancy). Equation (22) indicates that the capital return must be equal to the opportunity costs. Equation (23) shows that the firm must invest until the capital acquisition cost becomes equal to the capital value and equation (24) equates the benefits of additional capital services with the cost of replacing the worn out capital stock.

2.4 Wage and Hours Determination

Wage and hours worked are determined by the generalized *Nash*-bargaining solution. Indeed, the matching between an unemployed person and a firm who coordinate each other gives rise to a surplus which must be shared between the meeting pair. This sharing takes place at the match level through a bilateral and decentralized wage/hours negociation. Knowing that there are a representative household and a representative firm, we are located directly at the symmetric equilibrium solution of the model.

Formally, the surplus released by matching for a firm and a worker being the marginal value of employment, one can show (see Appendix B for details) that hourly real wage and hours worked are given by:

$$W_t = \xi \left(\Upsilon_t \left(1-\eta\right) \frac{Y_t}{N_t H_t} + \frac{\varsigma}{H_t} \frac{V_t}{U_t} \right) + (1-\xi) \frac{l\left(H_t\right)}{\lambda_t H_t} \tag{25}$$

$$\Upsilon_t (1-\eta)^2 \frac{Y_t}{N_t H_t} = \frac{l^t_{H_t}}{\lambda_t} \tag{26}$$

where $0 \leq \xi \leq 1$ is the relative bargaining power of workers.

2.5 Retailers

There is a continuum of monopolistically competitive retailers indexed by z on the unit interval. Each of them is infinitively lived and produces each period a differentiated final good $Y_t\left(z\right)$ with a technology that transforms one unit of wholesale goods into one unit of retail goods, so that $Y_t\left(z\right) = X_t^w$. Firms on the retail sector purchase output from wholesale producers at the price Υ_t (which becomes the firm's real marginal cost) and sell directly to households.

For a matter of convenience, we assume that the government and the wholesaler have the same optimal allocations for each differenciated goods as the household.[11] It implies that the aggregator's demand for each good $Y_t(z)$ - or equivalently the aggregate demand curve - is given by:

$$Y_t(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\epsilon} Y_t \tag{27}$$

Final output may then be either transformed into a single type of consumption good, invested, consumed by the government, used up in vacancy posting costs or capital adjustments costs. In particular, the economy-wide resource constraint is given by:

$$Y_t = C_t + I_t + G_t + \varsigma V_t + A_t \tag{28}$$

We introduce a nominal rigidity in the form of staggered price setting as developed by Calvo (1983). Each period, retailers may reset their prices with probability $(1-\phi)$, independent of the time elapsed since the last price revision. The draw is independant of history and we do not need to keep track of firms changing firms. The expected time over which the price is fixed, i.e. the expected waiting time for the next price adjustment is therefore $\frac{1}{1-\phi}$.[12] The fraction ϕ of firms are assumed to adjust their previous period's prices according to the following simple rule:

$$P_t = \pi_{t-1} P_{t-1} \tag{29}$$

As explained by Christiano et *alii* (2001), this specification is prefered because the standard specification $P_t = \bar{\pi} P_{t-1}$, where $\bar{\pi}$ is the steady state gross rate of inflation, does not generate sufficient inertia in inflation.

The objective function of the retailers who have the possibility to adjust their prices at period t implies that they choose $P_t^*(z)$ to maximise

$$E_t \sum_{j=o}^{\infty} (\phi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} \left[\frac{P_t^*(z)}{P_{t+j}} - \Upsilon_{t+j}\right] Y_{t+j}(z) \tag{30}$$

subject to the demand curve (27).

[11] At the cost of a more complicated notation, we could work with a third type of firms which agregates the final good.

[12] The average time a price remains fixed is given by $(1-\phi)\sum_{j=0}^{\infty}\phi^{j-1}j = \sum_{j=0}^{\infty}\phi^j = \frac{1}{1-\phi}$.

$\beta\frac{\lambda_{t+j}}{\lambda_t}$ is the relevant discount factor between t and $t+j$, where $\frac{\lambda_{t+j}}{\lambda_t}$ is the ratio of marginal utility of consumption at $t+j$ to marginal utility at t. $Y_{t+j}(z)$ is the firm's demand function for its output at time $t+j$ conditional on the price set at time t.

Consequently, after standard manipulations, the first-order condition associated to the maximization of (30) is given by:

$$P_t(z) = \frac{\epsilon}{\epsilon - 1} \frac{E_t \sum_{j=0}^{\infty} (\phi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} P_{t+j}^{\epsilon} Y_{t+j} \Upsilon_{t+j}}{E_t \sum_{j=0}^{\infty} (\phi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} P_{t+j}^{\epsilon-1} Y_{t+j}} \tag{31}$$

where $\frac{\epsilon}{\epsilon-1}$ is the steady state gross markup.

Finally, given that the fraction ϕ of the retailers that adjust in t choose the same new price $P_t^*(z)$ and the same level of output, and that the average price of firms that do not adjust is simply last period's price level $(\pi_{t-1}P_{t-1})$, then the dynamics of the consumption-based price index will obey,

$$P_t = \left[\phi\left(\pi_{t-1}P_{t-1}\right)^{1-\epsilon} + (1-\phi)\, P_t^*(z)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{32}$$

2.6 Fiscal and Monetary Policy

We now close the model by specifying the government's behaviour. The government conducts both fiscal and monetary policy (*via* a monetary authority). We assume that exogeneous government expenditures (G_t) are financed by lump-sum taxation, money and bonds creations. Because we do not consider distortionary taxes, the government faces the following budget constraint:

$$G_t = \frac{\Xi_t - \Xi_{t-1}}{P_t} + \frac{B_{t+1}/(1+i_t) - B_t}{P_t} + T_t \tag{33}$$

The law of motion for government spending is given by:

$$\ln(G_t) = \left(1-\rho_g\right)\ln\left(\bar{G}\right) + \rho_g \ln(G_{t-1}) + \varepsilon_t^g$$

where ε_t^g is a i.i.d. government spending shock, and $\rho_g < 1$.

We assume that the short run interest rate (i_t) is the monetary authority privileged instrument. The monetary authority adopts a feedback rule that has the nominal rate adjust to deviations of economy-wide inflation and output from their respective target values. In addition, we allow for partial adjustment to capture the interest rate smoothing that seems apparent in the data. The feedback rule is given by

$$(1+i_t) = (1+i_{t-1})^{\psi_i}\left[\left(\frac{P_t}{P_{t-1}}\right)^{\psi_\pi}\left(\frac{Y_t}{Y_t^p}\right)^{\psi_y}\right]^{1-\psi_i} \exp\left(\varepsilon_t^i\right) \tag{34}$$

where ε_t^i is an i.i.d monetary policy shock, Y_t^p is the potential output (this is the natural output resulting of any several types of real disturbances) and $\psi_i \in (0,1)\,, \psi_\pi > 1$ and $\psi_y > 0$.

We can notice that,

- even though the nominal interest rate is the monetary policy tool, the feedback rule indirectly determines Ξ_t since the central bank must adjust the money supply to satisfy money demand (equation (9)), given the choice of i_t;
- and, in equilibrium the excess of supply of bonds must be zero: $\bar{B} = 0$.

3 Quantitative Evaluation

The major goal of this study is to evaluate the contribution of introducing the search-theoretic framework into a monetary policy model. Towards this end, this section evaluates the performance of alternative models depending on degrees of rigidities. We present our choice of calibration and the comparisons between the models and their empirical counterparts using the unconditional second moments. Finally, one calculates the impulse response functions of the selected model. They show the transmission mechanisms of the structural shocks and illustrate the dynamic properties of the general model.

3.1 Solution and Model Parameterization

In order to get the model in a tractable form for conducting policy simulations we need to look for an approximate analytical solution by transformating the model into a system of log-linear difference equations. The strategy is to use a first order Taylor approximation around the steady state (with zero inflation) to replace the equations with approximations, which are linear in the log-deviations of the variables. Formally, let Z_t be a stationary random variable and $\bar{Z}$ its steady state. We denote z_t the logarithmic deviation of the variable Z_t from its steady state value :

$$\hat{z}_t = \ln(Z_t) - \ln(\bar{Z})$$

The resulting system, expressed in terms of percentage deviations around the steady-state is presented in Appendix C.

We then solve the model using the methods developed by Anderson and Moore (1985) which allows to compute solutions for rational expectations models. The algorithm determines whether the model has a unique solution, an infinity of solutions or no solutions at all, and produces a matrix codifying the linear constraints guaranteeing asymptotic convergence. The uniqueness of solutions to the system requires that the transition matrix characterizing the linear system have an appropriate number of explosive and stable eigenvalues (Blanchard and Khan conditions).

Calibration is used instead of estimation for two reasons. Firstly, the majority of the data relating to the labour market are incomplete or not available (hours worked or vacancies for example), it would then be necessary to estimate the model with a subset of the data what would introduce too much parameter estimation uncertainty. Secondly, as the Euro area is new, its behaviour can only be inferred from its past rather readily directly estimated from its previous joint behaviour of its component parts. Moreover, the problems of aggregation and the entry of new members make the quality of the data debatable and require additional adjustments.

The parameter values are assigned such that the Euro area model economy is around its stationary state over the period 1985-2000. The choice of the period of calibration answers a dual aim: to appoint the longest period, while avoiding too significant breaks. The Euro area data retained for the calibration result from the "augmented" database used by Fagan, Henry and Mestre (2001) for the Area Wide Model of the ECB.[13] The model is calibrated to quarterly data.

The discount rate and the coefficient of relative risk aversion appear in standard DSGE models. The subjective discount rate β is set equal to 0.99, which gives an annual steady state real interest rate equal to four percent. We assign values for the intertemporal elasticity of substitution (0.6) and elasticity of labour desutility (0.42) similar as ones estimated by Smets and Wouters (2002). Smets and Wouters (2002) or Sahuc (2002) considered values of h ranging between 0.57 and 0.96, we will retain an intermediate value of 0.75, more especially as these specifications selected were based on an external and not internal habit formation.

Concerning the matching and the labour market, we follow Petrongolo and Pissarides (2001) for the Cobb-Douglas matching function and set $\alpha = 0.5$, $\xi = 0.5$. According to the Euro area data, the NAIRU equals to 8.6% which implies a value for $\bar{N}$ of 0.914.

According to the AWM database, the share of government spending in the GDP $\left(\frac{\bar{G}}{\bar{Y}}\right)$ is equal to 16.22% and the share of consumption in GDP $\left(\frac{\bar{C}}{\bar{Y}}\right)$ is 62.56%. The rate of depreciation of the capital is fixed at 2% in order to make compatible the share of investment in GDP $\left(\frac{\bar{I}}{\bar{Y}} = 20.22\%\right)$ and the coefficient of the capital $\left(\frac{\bar{K}}{\bar{Y}} = 9.68\right)$.

[13]The data concerning years 1999 and 2000 were added to the database available.

The capital share parameter was obtained by estimating a production function by OLS. The estimated parameter could not reject $\eta = 0.35$. Moreover, following the literature, we set the elasticity of marginal depreciation (d) to unity.

The reaction function of the monetary authority is assumed to be an inertial Taylor rule with usual parameter values (see Clarida *et al.* (1998)): $\psi_i = 0.9, \psi_\pi = 1.5$ and $\psi_y = 0.5$.

The degree of nominal rigidity determined by the fraction of firms that do not adjust their price (ϕ) and the degree of real rigidity emanating from the labour market *via* the two probabilities τ and ϱ, are more difficult to gauge. They will be taken as free parameters and we will let the analysis of the autocorrelations given us more information.

Table 1 presents an overview of the values of the calibrated parameters as they were used in the simulations.

3.2 Unconditional Second Moments

An informal assessment of the quantitative performance of the model's assumed data generating processes and dynamic propagational mechanisms can be conducted by comparing the second moments of the simulated series of certain key macroeconomic variables implied by the benchmark model with their observable counterparts. That also will enable us to evaluate the degrees of nominal and real rigidity necessary for the Euro area.

The sample moments are calculated for Hodrick-Prescott filtered data and we use Monte Carlo simulation of the model to produce an average of 10000 simulated sets of time series with length of 60. We simulated the model for four sets of parameters depending on the level of price and labour market rigidities:

1. $\phi = 0.75$ (prices are fixed for one year), $\varrho = 0.5$ (the duration of unemployment is 6 months) and $\tau = 1$ (the duration of vacancies is three months);

2. $\phi = 0.75$ (prices are fixed for one year), $\varrho = 0.25$ (the duration of unemployment is 12 months) and $\tau = 0.5$ (the duration of vacancies is six months);

3. $\phi = 0.9$ (prices are fixed for two years and half), $\varrho = 0.5$ (the duration of unemployment is 6 months) and $\tau = 1$ (the duration of vacancies is three months);

4. $\phi = 0.9$ (prices are fixed for two years and half), $\varrho = 0.25$ (the duration of unemployment is 12 months) and $\tau = 0.5$ (the duration of vacancies is six months).

Results are shown in Figures 1a to 1d. The grey bars represent the data cross correlations and the black ones are those implied by the simulated model. It is obvious to remark that the model with a standard degree of nominal rigidity ($\phi = 0.75$) is not able to generate the sample dynamic cross correlations although assuming a higher degree of real rigidity improves the general fit of the dynamic cross correlations.

In fact, we have rely on a very high degree of price rigidity ($\phi = 0.9$) in order to match the data. Especially when we introduce high durations of unemployment and vacancies ($\varrho = 0.25$ and $\tau = 0.5$), the lag and lead cross correlations for almost all the variables in the model are quite close to those of the data in sign and magnitude. For example, we can observe that consumption, investment, employment are strongly procyclical while capital or interest rate are acyclical. The model performs reasonably well with respect to the unemployment. Correlations of the unemployment with output are generally countercyclical as in the data and the negative correlation between inflation and unemployment reflects a Phillips curve relation.

This is not surprising as it is a usual feature in models including short run non-neutrality of money and labour market search (see for example Chéron and Langot (1999) or Cooley and Quadrini (1999)). As emphasized in the former paper, the stylized fact associated with the Phillips curve is viewed as an important tool in the conduct of the monetary policy. Thus, a model interesting in the monetary policy debate, like this one, must qualitatively account for the Phillips-curve.

Although we do not have a series of vacancies, Chart 2 of the ECB document (2002, p17) allows us to say that Euro area data display a strong negative correlation between vacancies and unemployment.[14] This fact is reflected in our simulated cross correlations (not represented here but available) and so well represented by our theoretical model. This means that the matching process assumption is sufficient to describe the dynamic of the frictional unemployment summarized by the Beveridge curve. Figure 2 shows the simulated Phillips and Beveridge curves.

However, the most serious weakness of the model with staggered price and labour market search is its ability to generate a wrong pattern for real wages. The divergence between data and model suggest that future works could focus on modifying the wage equation.

[14] The Beveridge curve for the euro area provided by the ECB is proxied by the aggregate of nine countries covering 64% of the zone.

Then, we keep the specification inducing the highest degrees of nominal and real rigidities in the following subsection.

3.3 Impulse Responses

This subsection presents the dynamics of the model and more specifically the impulse responses to one-standard deviation shocks to all the model's underlying shocks. The impulse reponses are shown in Figures 3 through 6. In each case, we simulate the response to a positive innovation of 1% in the relevant forcing variable's process. This leads to persistent increases in the level of interest rate, the level of technology, the level of government spending and the level of preference, with the degree of persistence depending on the $AR(1)$ coefficients of the relevant stochastic processes.

The impulse response functions confirm the presence of a Phillips and Beveridge curves relation.

3.3.1 Monetary Policy Shock

Figure 3 reports the responses to a 1% increase in the nominal interest rate. This shock is a perturbation of the monetary policy rule and therefore, it triggers the correction mechanisms implied by it.

Following this shock, households reduce their consumer spending (-7%) as real interest rate increases (0.6%). Firms respond to the hike in interest rate by strongly reducing their investment spending (-26%) and decreasing hours per worker (-3.5%) and capital utilisation rather than employment. This result can be explained by the fact that hours are the only production factor which is not predetermined. This causes a large decrease in marginal cost. In terms of contributions to GDP, the decline in consumption is stronger than that in investment. Inflation decreases slowly due to price rigidities.

Since vacancies reflect recruiting effort and move in response to the expectation of the profitability of a successful match, they drop (-8%) due to the decrease of the marginal cost (-8%). However, we can notice that this variable is the first to start its final hump shape pattern. The fall of employment (-0.25%) induces an increase of the probability that a vacancy is filled which tends to increase expected profits and then vacancies. This effect dominates only after some periods which explains the particular dynamics of vacancies. As emphasized by Chéron and Langot (2002), real wages experience a large decrease (-8%) because their dynamics is strongly procyclical and more precisely in our model, they are too strongly related to the vacancies-unemployment ratio.

All variables decay slowly back to their steady-state values, and the dynamic responses display the typical hump shaped pattern.

As we have just seen it, a key mechanism is that firms mainly adjust total hours ($N_t H_t$) via hours per worker (the intensive margin). Although this effect is too important in our study, it is not disconnected from reality. As Figure 7 for the three larger countries of the zone euro shows it, the evolution of the annual growth rate of employment is smoothed more than that of hours worked.[15] These last remain more volatile.

3.3.2 Technology Shock

Figure 4 shows the effects of an improvement in total factor productivity. Although the initial output response is slightly negative, the effect becomes positive after two quarters and keeps building up gradually (0.8%). The shock raises consumption (0.3%) since households increase their spending. Their real wages are indexed to productivity and increase gradually but significantly (0.5%). As noted before, they follow in more the vacancies-unemployment ratio multipliying the preceding mechanical effect.

Since output rises by less than potential output, the resulting negative output gap puts downward pressure on prices, which allows the monetary authorities to reduce interest rate. Hence, monetary policy is accommodating, and prices do not change much (the response of inflation is negative (-0.10%) and exhibits persistence). Investment and vacancies also rise but only after an initial fall due to the presence of a small crowding-out effect.

Two features must be noted concerning the employment dynamics. Firstly, given that the amount of nominal price rigidity imparted by the nominal and real frictions is very substantial, firms can meet their demand with less labour input (total hours fall (-0.7%)) given the increase in productivity. Our model is then consistent with the findings of Gali (1999) on OECD countries and Smets and Wouters (2002) on Euro area data. Contrary to the Dotsey's (1999) claim, one can produce a negative correlation between productivity and total hours in the presence of an interest rate rule and sticky price. Secondly, contrary to the evidence, firms mainly adjust total hours *via* individual hours and not *via* employment.

[15] As we just have annual and not quarterly data, we have not been able to compare the empirical hours\output correlations with those generated by the model.

3.3.3 Shock to Government Spending

Figure 5 plots the dynamic responses of selected variables to a shock to government consumption. Such a shock always increases output (0.14%), with more persistent shocks leading to greater increases. That is, we observe multiplier effects with persistent government spending shocks. Negative interest rate effects bring private consumption below its steady state value (-0.08%) while following a hump-shaped pattern (due to the presence of habit formation), and then consumption gradually returns to its steady state value. Under the demand shock, there exists excess demand in the goods market prevailing interest rate, and the interest rate must go up to clear the goods market (0.01%). Then, capital stock and investment strongly fall (-0.24% and –0.30% respectively).

With a positive income effect on leisure, persistent changes in government spending always have a positive effect on total hours worked. But hours per worker and employment respond differently. Hours worked are determined by negociation whereas employment is determined by job destruction and creation in the labour market. Changes in employment in this model depend crucially on the decision by the firm to create a vacant job at some cost. An increase in government spending unambiguously raises hours worked per worker (0.11%), but may increase or decrease the employment. The firm increases or decreases job openings based on the expected value of a hired worker to the firm. A higher value of a hired worker to the firm encourages the firm to create more vacancies. The two factors affecting the value is the real interest rate and the global surplus in each period. We observe that even though global surplus increases to a demand shock, the negative real interest rate effect on the value of a hired worker still dominates the positive economic rent effect, thus vacancies decrease (-0.05%) just like the employment (-0.005%).

3.3.4 Preference Shock

Figure 6 reports the responses to an increase on household's preference. The shock acts directly on consumption by increasing it by 0.7% and makes it possible to increase the output of 0.3%. We notice that the preference shock has a stronger impact on output than the government spending one.

Just like the preceding demand shock, it is clear that increased overall demand puts upward pressure on real factor prices, real marginal cost and inflation. In order to stem these inflationary pressures, real interest rate rises inducing a significant negative crowding-out effect on investment (–1%). The increase in capacity necessary to satisfy the increased demand is delivered by a raise in the utilisation of installed capital (so a decrease in capital during several periods) and an increase in total hours.

Here again, the matching mechanism that determines employment implies an increase in hours per worker (0.35%) and in employment (0.02%) as demonstrate by several VAR models in the literature.

3.4 Some Lessons for the Monetary Policy

To finish, we have to clarify two important points for the monetary policy decisions.

Firstly, since the introduction of the labour market but especially of these frictions has a strong impact on the overall dynamics of the model, the decisions of policy can be very distant according to whether a simple model (without labour market) or a more complete one is looked at. Figure 8 shows the responses of output, interest rate and inflation following the three main structural shocks. The dotted lines responses are those of a simple three-equations model composed by the IS and Phillips curves and the inertial interest rate rule. The other responses are those of our model.

It is rather clear that the complete model responses are much more persistent than the simple model ones. The introduction of frictions other than those on the market of goods (but also adjustment costs on capital) accentuates the endogenous persistence. Consequently, the monetary authorities which would be based on a model without labour market would have all the chances to be mistaken in modifying their interest rate. The stabilization of the economy would be much longer than than they hoped.

Secondly, the comparison of several monetary policy rules makes it possible to highlight the fact that an inflation targeting rule gives less good results in term of stabilisation than a Taylor type rule. This is not a new result since it is obvious that adding additionnal variables in the rule allows to improve its stabilising qualities. However, to put a more important weight on the production gives better results (see for example the rule estimated by Sahuc (2002)).

Moreover, just like one does it concerning the financial market, one has the right to wonder whether the monetary authorities should include a variable of tension of the labour market, such as the unemployment rate, in their monetary policy rule. Our simulations show that the introduction of the unemployment in the rule (with the same weight as the output for example) helps slightly to stabilise the inflation more rapidly and has no significative effect on the other variables stabilisation. Finally, we can say that augmenting the rule with a labour market variable is not specially an improvement.

4 Summary and Concluding Remarks

Previous works using competitive DSGE model have provided reasonable descriptions of the data on real variables. However, such works did not capture at all or badly the labour market features although we know that the functioning of the labour market affects business cycle dynamics and is crucial for the monetary policy decisions. It would appear imperative to model unemployment as the outcome of an equilibrium process.

This paper aims at filling this gap in developing an optimising-based monetary policy model with capital, sticky prices and a non-walrasian labour market in the form of a simple labour market search mechanism. This enables us to study the respective role of labour maket frictions and nominal frictions in accounting for the empirical second moments observed on the Euro area data.

We have shown that the unconditionnal second moments generated by the calibrated model are close to those in the Euro area, except regarding the real wage dynamics, when both a high degree of nominal and labour market frictions are assumed. This indicates that labour market frictions does not act as a substitute for nominal rigidities but as a necessary complement. Thus, as in Smets and Wouters (2002), our model is not able to adress the shortcoming of requiring an implausible degree of price rigidity in order to match data.

Contrary to the former papers, our model allows us the possibility to investigate the theoretical determinants of the extensive and intensive margin on the labour market. Unfortunately, we are not able to match the empirical VAR responses of individual hours worked relative to employment. Indeed, we find that hours per worker is a *too dominant* leading indicator in the sense that their volatility is greater than those of employment. Following a structural shock, hours per worker are the crucial variable of adjustment for firms. On this side, introducing a variable capital utilisation rate helps solving part of this weakness since hours worked are no longer the only non-predetermined production factor.

We have shown the ability of our model to reproduce the labour market stylized facts characterized by the Beveridge and Phillips curves, but also its inability to generate the observed real wage pattern. Allowing for consumption differences between unemployed and employed agent can help us to correct this drawback as shown in Chéron and Langot (2002).

Finally, it might be interesting for further research to use this type of model to investigate the impact of labour market frictions on the derivation of the optimal monetary policy and more particularly their effects on the global welfare.

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Appendix A: Perfect Insurance System

Households face up to two states on the labour market at each period: they may be employed or unemployed.

When the household j works, his utility, U_j^n, is given by

$$U_j^n = u^n\left(C_{j,t}^n, C_{j,t-1}^n\right) + v^n\left(\frac{\Xi_{j,t}^n}{P_t}\right) - l^n\left(H_{j,t}\right) \tag{35}$$

When the household j is unemployed, his utility, U_j^u, is defined as

$$U_j^u = u^u\left(C_{j,t}^u, C_{j,t-1}^u\right) + v^u\left(\frac{\Xi_{j,t}^u}{P_t}\right) \tag{36}$$

Because the individual doesn't work, his instantaneous work desutility $(l\left(H_{j,t}\right))$ clearaly disappears.

We can derive the household's expected utility as a weighted sum of these two utilities conditionned by the states,

$$U_{j,t} = N_t\left(U_j^n\right) + (1 - N_t)\left(U_j^u\right)$$

where the employment N_t is the probability to be employed.

The household chooses the sequence $\left\{C_{j,t}^n, C_{j,t}^u, \Xi_{j,t}^n, \Xi_{j,t}^u, B_{j,t}^n, B_{j,t}^u\right\}$ and a level of unemployment insurance $INS_{j,t}$ subject to the budget constraints associated to the states on the labour market:

$$C_{j,t}^n + \frac{\Xi_{j,t}^n}{P_t} + \frac{B_{j,t+1}^n}{(1+i_t)P_t} \leq W_{j,t}H_{j,t} + \frac{B_{j,t}^n}{P_t} + \frac{\Xi_{j,t-1}^n}{P_t} - \frac{T_t}{P_t} + \Pi_t^r + \Pi_t^w - \varrho_t INS_{j,t}$$

$$C_{j,t}^u + \frac{\Xi_{j,t}^u}{P_t} + \frac{B_{j,t+1}^u}{(1+i_t)P_t} \leq \frac{B_{j,t}^u}{P_t} + \frac{\Xi_{j,t-1}^u}{P_t} - \frac{T_t}{P_t} + \Pi_t^r + \Pi_t^w + (1 - \varrho_t) INS_{j,t}$$

where ϱ_t is the price of insurance.

The first order conditions are:

$$(C_t^e) \qquad \lambda_{j,t}^e = \frac{\partial u^e\left(C_{j,t}^e, C_{j,t-1}^e\right)}{\partial C_{j,t}^e} + \beta\frac{\partial u^e\left(C_{j,t+1}^e, C_{j,t}^e\right)}{\partial C_{j,t}^e},\ \forall e = n, u$$

$$(M_t^e) \qquad \frac{\lambda_{i,t}^e}{P_t} - \beta E_t\frac{\lambda_{i,t+1}^e}{P_{t+1}} = \frac{\partial v^e\left(\frac{\Xi_{j,t}^e}{P_t}\right)}{\partial \Xi_{j,t}^e},\ \forall e = n, u$$

$$(B_t^e) \qquad \lambda_{j,t}^e = (1+i_t)\beta E_t\frac{\lambda_{i,t+1}^e P_t}{P_{t+1}},\ \forall e = n, u$$

$$(INS_{j,t}) \qquad N_t \varrho_t \lambda^n_{j,t} = \ (1 - N_t)(1 - \varrho_t)\, \lambda^u_{j,t}$$

The insurance company receives the assurance premium from the worker and payes the indemnities for the unemployed household such as his profit flow is given by:

$$\Pi^{INS} = \varrho_t INS_t - (1 - N_t) INS_t$$

Since the free entry condition holds on the unemployment insurance market, the price of the unemployment contract is $\varrho_t = (1 - N_t)$. Together with the first order conditions this implies that

$$\lambda^u_{j,t} = \lambda^n_{j,t} \quad \forall t$$

$$\Xi^u_{j,t} = \Xi^n_{j,t} \quad \forall t$$

$$B^u_{j,t} = B^n_{j,t} \quad \forall t$$

$$INS_t = w_t h_t \quad \forall t$$

Consequently, households choose to be fully insured, and all of them have the same stock of bonds and money. The preferences adopted enable us to distinguish household's consumption across the different states on the labour market, so by simplicity, we impose $C^u_{j,t} = C^n_{j,t}$ at each period. It is now straightforward to show that we can work with a representative household.

Appendix B: Real Wage and Hours Worked Derivations

Let Ω_t^F be the value function of the firm in period t, for a wage W_t the firm's expected return from a job is given by the marginal value of employment:

$$\begin{aligned}
\frac{\partial \Omega_t^F}{\partial N_t} &= \Upsilon_t(1-\eta)\frac{Y_t}{N_t} - W_t H_t + \beta \frac{\lambda_{t+1}}{\lambda_t}\frac{\partial N_{t+1}}{\partial N_t}\frac{\partial \Omega_{t+1}^F}{\partial N_{t+1}} \\
&= \Upsilon_t(1-\eta)\frac{Y_t}{N_t} - W_t H_t + \beta \frac{\lambda_{t+1}}{\lambda_t}(1-s)\frac{\partial \Omega_{t+1}^F}{\partial N_{t+1}} \\
&= \Upsilon_t(1-\eta)\frac{Y_t}{N_t} - W_t H_t + \frac{\varsigma}{\tau_t}(1-s)
\end{aligned}$$

Let Ω_t^H be the value function of the household in period t, the household's expected return from a job is given by the marginal value of employment:

$$\begin{aligned}
\frac{\partial \Omega_t^H}{\partial N_t} &= \lambda_t W_t H_t - l\left(H_{t+i}\right) + \beta \frac{\partial N_{t+1}}{\partial N_t}\frac{\partial \Omega_{t+1}^H}{\partial N_{t+1}} \\
&= \lambda_t W_t H_t - l\left(H_{t+i}\right) + \beta\left(1-s-\varrho_t\right)\frac{\partial \Omega_{t+1}^H}{\partial N_{t+1}}
\end{aligned}$$

A realized job match yields some pure economic rent, which is equal to the sum of the expected search costs of the firm and the worker. We assume that the monopoly rent is shared according to the Nash solution to a bargaining problem so that the real wage is determined according to the maximization of the following Nash criterion where the suplus of each agents is given by the marginal value of unemployment measured in term of consumption goods.

$$W_t = \arg\max_{\{W_t\}} \left(\frac{\partial \Omega_t^H}{\lambda_t \partial N_t}\right)^{\xi}\left(\frac{\partial \Omega_t^F}{\partial N_t}\right)^{(1-\xi)}$$

The first order condition gives the following surplus sharing rule:

$$\xi \frac{\partial \Omega_t^F}{\partial N_t} = (1-\xi)\frac{\partial \Omega_t^H}{\lambda_t \partial N_t} \tag{37}$$

Iterating (37) one period in the future and multiplying by $\frac{\beta}{\lambda_t}$ we obtain:

$$\xi \beta E_t\left(\frac{\lambda_{t+1}\partial \Omega_{t+1}^F}{\lambda_t \partial N_{t+1}}\right) = (1-\xi)\beta E_t\left(\frac{\partial \Omega_{t+1}^H}{\lambda_t \partial N_{t+1}}\right)$$

Using the fact that $\beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial \Omega_{t+1}^F}{\partial N_{t+1}}\right) = \frac{\varsigma}{\tau_t}$, we have:

$$\frac{\varsigma}{\tau_t} = \frac{(1-\xi)}{\xi}\beta\frac{\partial\Omega^H_{t+1}}{\lambda_t\partial N_{t+1}}$$

By combining this last expression with the expressions of the surpluses and the sharing rule we can derive the wage expression:

$$W_t = \xi\left(\Upsilon_t\,(1-\eta)\,\frac{Y_t}{N_t H_t} + \frac{\varsigma}{H_t}\frac{V_t}{U_t}\right) + (1-\xi)\,\frac{l\,(H_t)}{\lambda_t H_t} \tag{38}$$

Then hours worked are determined by maximizing the joint surplus (S_t),

$$S_t = \frac{\partial\Omega^H_t}{\lambda_t\partial N_t} + \frac{\partial\Omega^F_t}{\partial N_t}$$

so the first order condition is

$$\frac{\partial S_t}{\partial H_t} = \Upsilon_t(1-\eta)^2\frac{Y_t}{N_t H_t} - \frac{\partial l\,(H_t)}{\lambda_t\partial H_t} = 0$$

Finally we obtain:

$$\Upsilon_t(1-\eta)^2\frac{Y_t}{N_t H_t} = \frac{\partial l\,(H_t)}{\lambda_t\partial H_t} \tag{39}$$

Appendix C: The Log-Linearised Model

- Consumption equation

$$\hat{c}_t = \frac{h(\sigma_c - 1)}{\beta h^2 \sigma_c - \beta h^2 + \beta h \sigma_c - 1}\hat{c}_{t-1} + \frac{\beta h(\sigma_c - 1)}{\beta h^2 \sigma_c - \beta h^2 + \beta h \sigma_c - 1}E_t\hat{c}_{t+1} + \frac{\sigma_c(1-\beta h)}{\beta h^2 \sigma_c - \beta h^2 + \beta h \sigma_c - 1}\hat{\lambda}_t - \frac{\sigma_c\left(1-\beta h \rho_p\right)}{\beta h^2 \sigma_c - \beta h^2 + \beta h \sigma_c - 1}\varepsilon_t^p$$

- Euler equation

$$\hat{\lambda}_t = E_t\hat{\lambda}_{t+1} + \hat{\imath}_t - E_t\hat{\pi}_{t+1}$$

- Price equation

$$\hat{\pi}_t = \frac{\beta}{1+\beta}E_t\hat{\pi}_{t+1} + \frac{1}{1+\beta}\hat{\pi}_{t-1} + \frac{(1-\beta\phi)(1-\phi)}{(1+\beta)\phi}\hat{\Upsilon}_t$$

- Hours equation

$$\hat{h}_t = \frac{1}{(1-\eta)}\hat{y}_t - \frac{\eta}{(1-\eta)}\left(\hat{k}_t + \hat{\varkappa}_t\right) - \frac{1}{(1-\eta)}\varepsilon_t^a - \hat{n}_t$$

- Capital accumulation

$$\hat{k}_{t+1} = \left(1-\bar{\delta}\right)\hat{k}_t + \bar{\delta}\left(\hat{I}_t - d\hat{\varkappa}_t\right)$$

- Aggregate constraint

$$\hat{y}_t = \frac{\bar{C}}{\bar{Y}}\hat{c}_t + \frac{\bar{I}}{\bar{Y}}\hat{I}_t + \frac{\bar{G}}{\bar{Y}}\hat{g}_t + \frac{\varsigma\bar{V}}{\bar{Y}}\hat{v}_t$$

- Investment equation

$$\hat{I}_t = \left(\frac{\beta\eta\bar{\Upsilon}}{\Theta\bar{\delta}}\frac{\bar{Y}}{\bar{K}} + \frac{\beta(1-\bar{\delta})}{\Theta\bar{\delta}}\right)\left(E_t\hat{\lambda}_{t+1} - \hat{\lambda}_t\right) + \frac{\beta\eta\bar{\Upsilon}\bar{Y}}{\Theta\bar{\delta}\bar{K}}\left(E_t\hat{\Upsilon}_{t+1} + E_t\hat{y}_{t+1}\right) - \beta\left(1 + \frac{\eta\bar{\Upsilon}\bar{Y}}{\Theta\bar{\delta}\bar{K}}\right)E_t\hat{k}_{t+1} + \hat{k}_t + d\hat{\varkappa}_t - d\left(\frac{1+\Theta}{\Theta}\right)E_t\hat{\varkappa}_{t+1} + \beta E_t\hat{I}_{t+1}$$

- Employment equation

$$\hat{n}_{t+1} = (1-s)\hat{n}_t + s\hat{m}_t$$

- Marginal costs

$$\hat{\Upsilon}_t = \frac{(1+\sigma_n)}{\sigma_n}\hat{h}_t - \hat{\lambda}_t - \hat{y}_t + \hat{n}_t$$

- Job vacancies

$$\hat{v}_t = \hat{m}_t + \frac{\beta\tau(1-\eta)\bar{\Upsilon}\bar{Y}}{\varsigma\bar{N}}\left(E_t\hat{\Upsilon}_{t+1} + E_t\hat{y}_{t+1} - E_t\hat{n}_{t+1}\right) - \frac{\beta\tau\bar{W}\bar{H}}{\varsigma}\left(E_t\hat{w}_{t+1} + E_t\hat{h}_{t+1}\right)$$
$$+\beta(1-s)\left(E_t\hat{v}_{t+1} - E_t\hat{m}_{t+1}\right) + E_t\hat{\lambda}_{t+1} - \hat{\lambda}_t$$

- Capacity utilisation

$$\hat{\varkappa}_t = \frac{1}{d}\left(\hat{\Upsilon}_t + \hat{y}_t - \hat{k}_t\right)$$

- Unemployment

$$\hat{u}_t = -\frac{\bar{N}}{\bar{U}}\hat{n}_t$$

- Wage evolution

$$\hat{w}_t = \frac{\xi(1-\eta)\bar{\Upsilon}\bar{Y}}{\bar{W}\bar{H}\bar{N}}\left(\hat{\Upsilon}_t + \hat{y}_t - \hat{n}_t\right) + \frac{\xi\varsigma\bar{V}}{\bar{W}\bar{H}\bar{U}}(\hat{v}_t - \hat{u}_t) - \frac{\sigma_n(1-\xi)(1-\eta)^2\bar{\Upsilon}\bar{Y}}{(1+\sigma_n)\bar{W}\bar{H}\bar{N}}\hat{\lambda}_t$$
$$+\left(\frac{(1-\xi)(1-\eta)^2\bar{\Upsilon}\bar{Y}}{(1+\sigma_n)\bar{W}\bar{H}\bar{N}} - \frac{\xi(1-\eta)\bar{\Upsilon}\bar{Y}}{\bar{W}\bar{H}\bar{N}} - \frac{\xi\varsigma\bar{V}}{\bar{W}\bar{H}\bar{U}}\right)\hat{h}_t$$

- Government spending

$$\hat{g}_t = \rho_g\hat{g}_{t-1} + \varepsilon_t^g$$

- Interest rate rule

$$\hat{\imath}_t = \psi_i\hat{\imath}_{t-1} + (1-\psi_i)\left[\psi_\pi\hat{\pi}_t + \psi_y\left(\hat{y}_t - \hat{y}_t^p\right)\right] + \varepsilon_t^i$$

- Matching function

$$\hat{m}_t = \alpha\hat{u}_t + (1-\alpha)\hat{v}_t$$

- Preference shock

$$\hat{\varepsilon}_t^p = \rho_p\hat{\varepsilon}_{t-1}^p + e_{1,t}$$

- Technology shock

$$\hat{\varepsilon}_t^a = \rho_a\hat{\varepsilon}_{t-1}^a + e_{2,t}$$

Description	Parameter	Quarterly Value
Intertemporal elasticity of substitution	σ_c	0.600
Elasticity of work effort	σ_n	0.420
Discount factor	β	0.990
Habit formation parameter	h	0.750
Probability of changing price	ϕ	0.750-0.900
Capital share	η	0.350
Rate of depreciation	δ	0.020
Price elasticity of demand	ϵ	11
Capital adjustment cost parameter	Θ	6
Utilisation rate elasticity	d	1
Vacancy cost parameter	ς	0.100
Bargaining power	ξ	0.500
Elasticity in the matching function	α	0.500
Job separation rate	s	0.030
Lag interest rate coefficient in the rule	ψ_i	0.900
Inflation coefficient in the rule	ψ_π	1.500
Output gap coefficient in the rule	ψ_y	0.500
Unemployment rate	$\overline{U}$	0.086
AR(1) parameter, preference shock	ρ_p	0.850
AR(1) parameter, technology shock	ρ_a	0.950
AR(1) parameter, governement spending shock	ρ_g	0.950
Variance of the interest rate shock	$\sigma^2_{\varepsilon_i}$	0.100
Variance of the preference shock	$\sigma^2_{\varepsilon_p}$	0.350
Variance of the technology shock	$\sigma^2_{\varepsilon_a}$	0.600
Variance of the government spending shock	$\sigma^2_{\varepsilon_g}$	0.300

Table 1: Euro Area Model Calibration

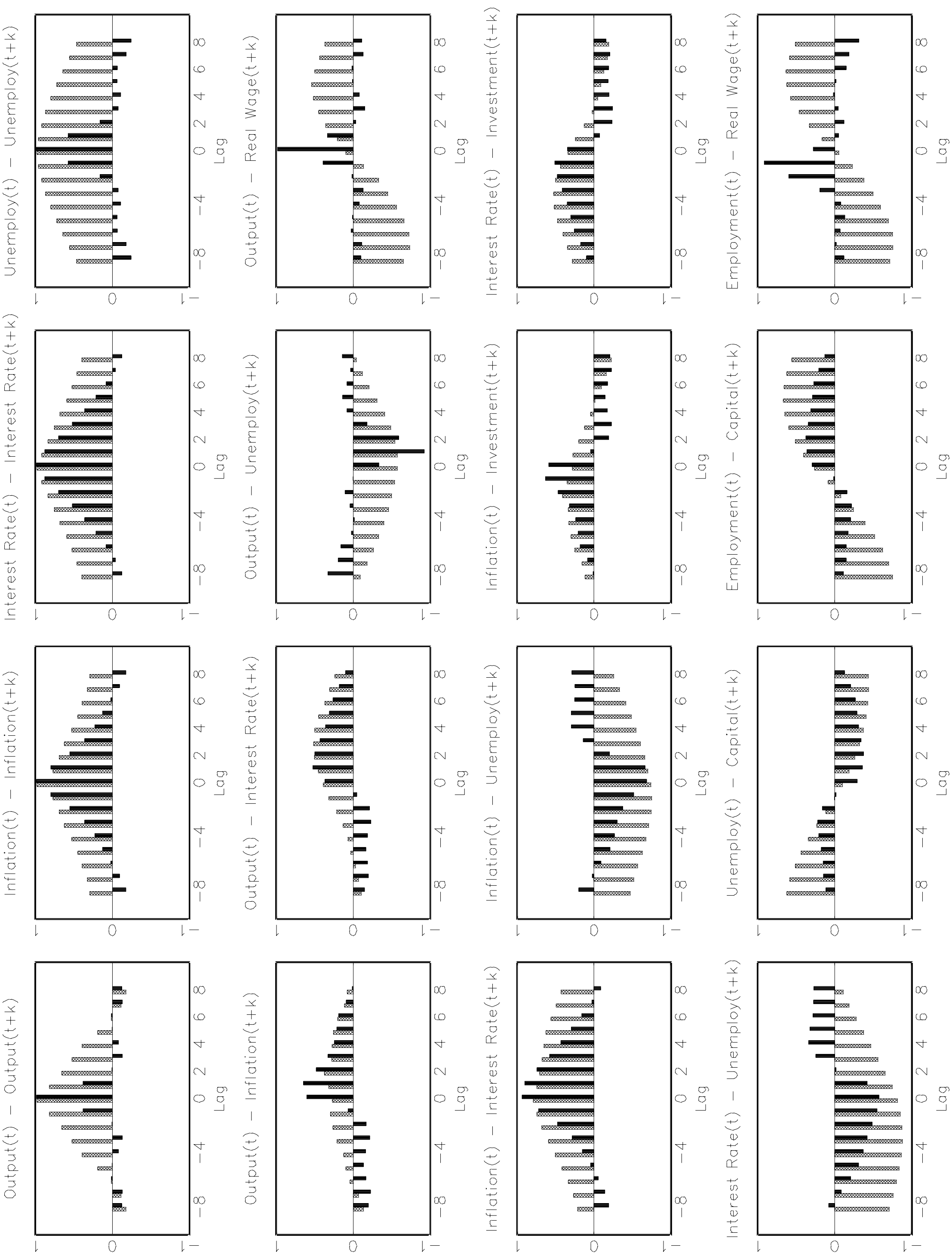

Figure 1a: Cross Correlations of the DSGE model and the data

($\phi = 0.7, \varrho = 0.5$ and $\tau = 1$)

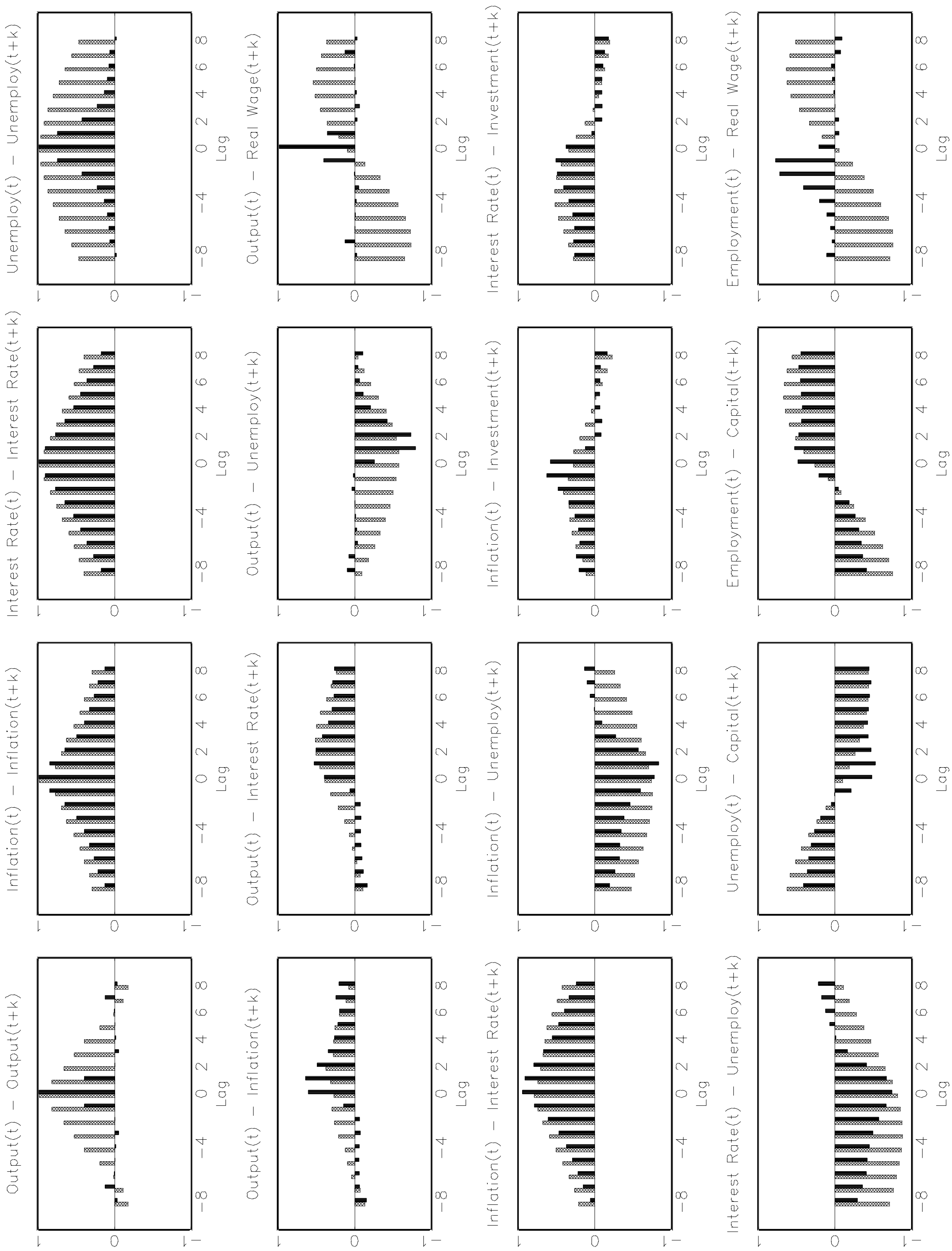

Figure 1b: Cross Correlations of the DSGE model and the data
($\phi = 0.7, \varrho = 0.25$ and $\tau = 0.5$)

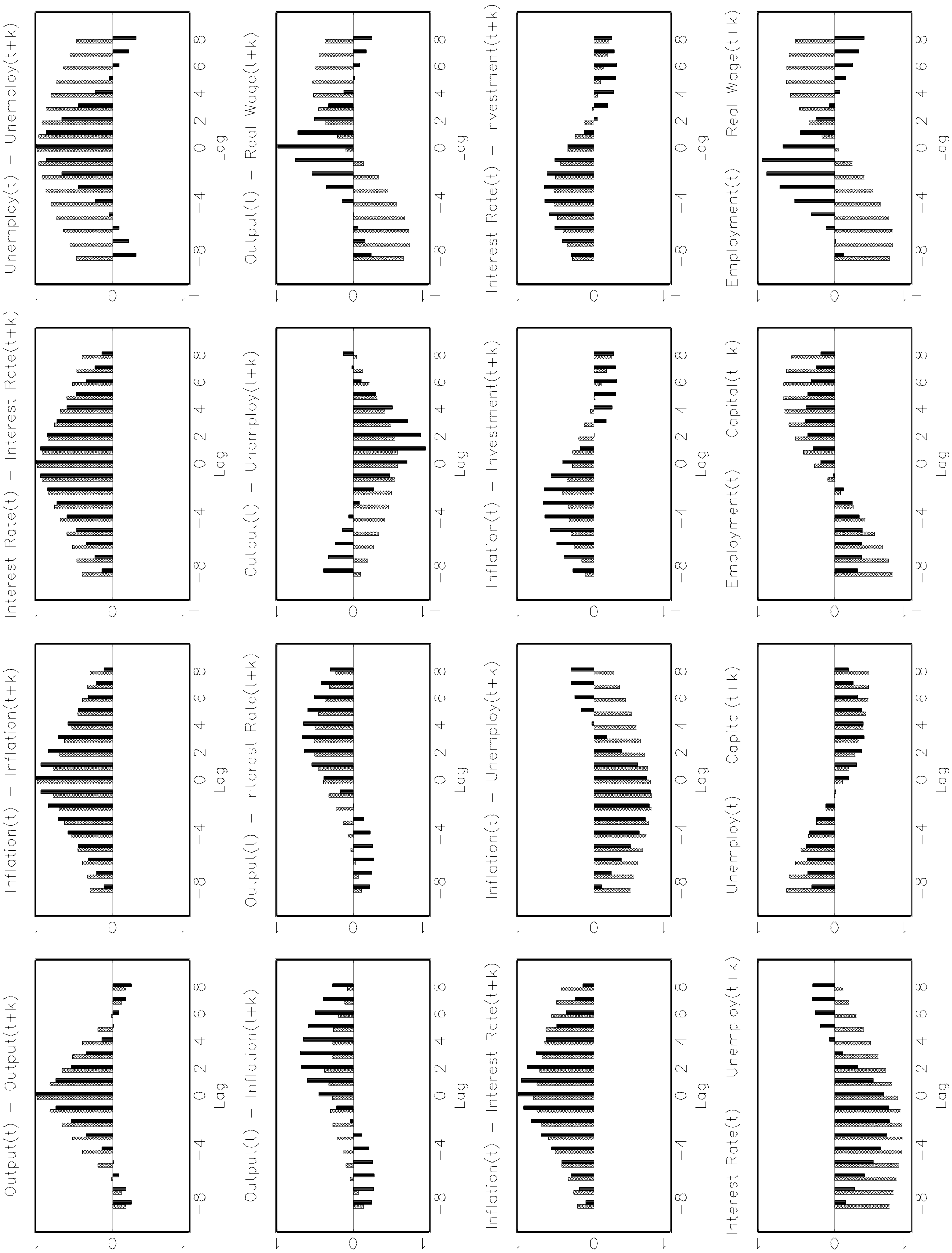

Figure 1c: Cross Correlations of the DSGE model and the data

($\phi = 0.9, \varrho = 0.5$ and $\tau = 1$)

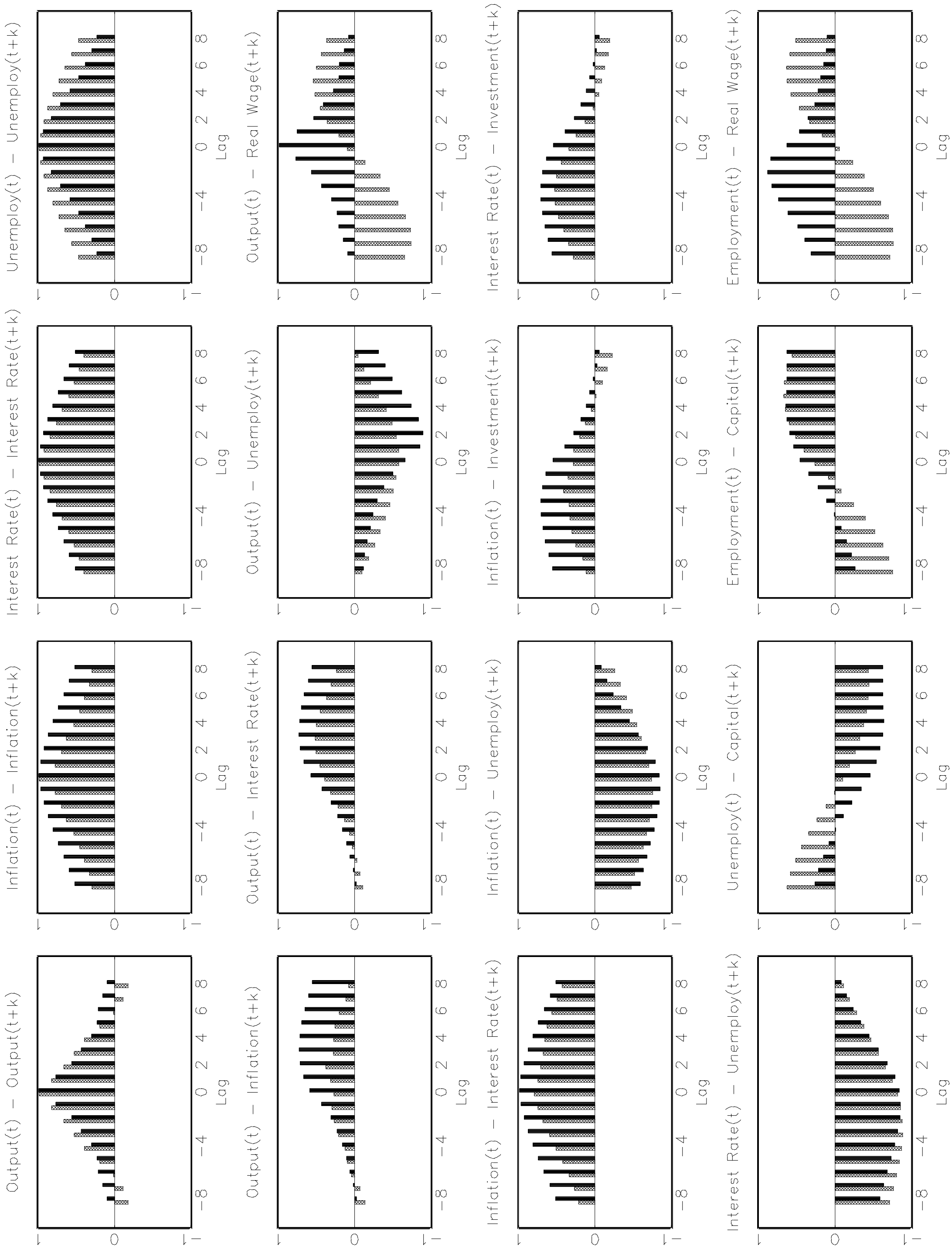

Figure 1d: Cross Correlations of the DSGE model and the data

($\phi = 0.9, \varrho = 0.25$ and $\tau = 0.5$)

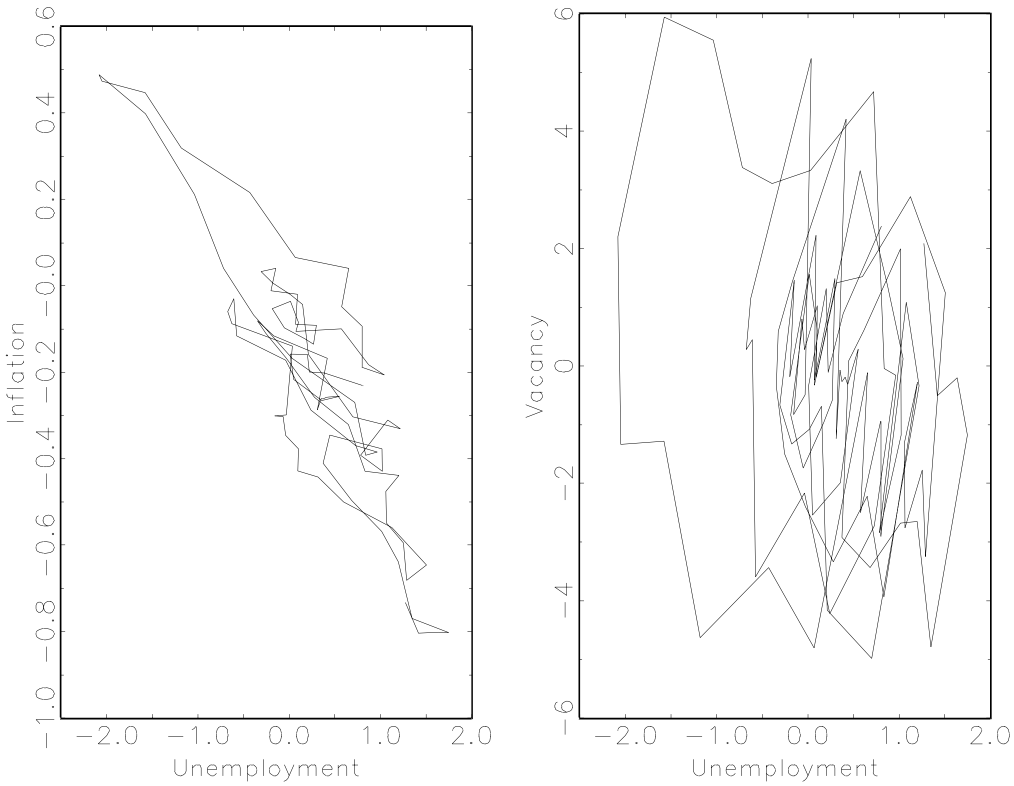

Figure 2: Simulated Phillips and Beveridge curves

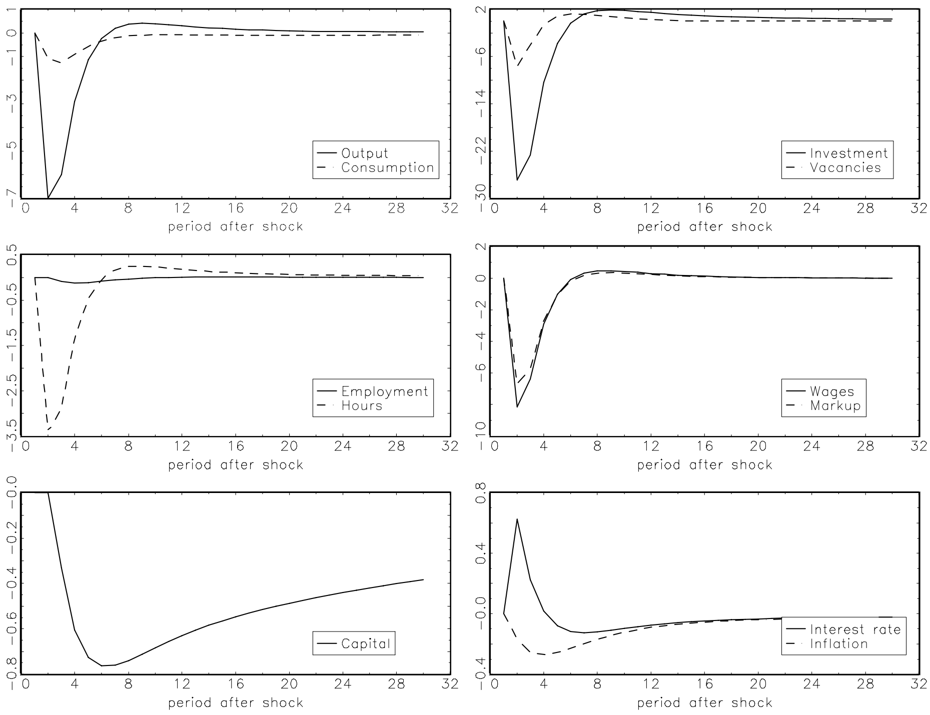

Figure 3: Responses to a monetary policy shock

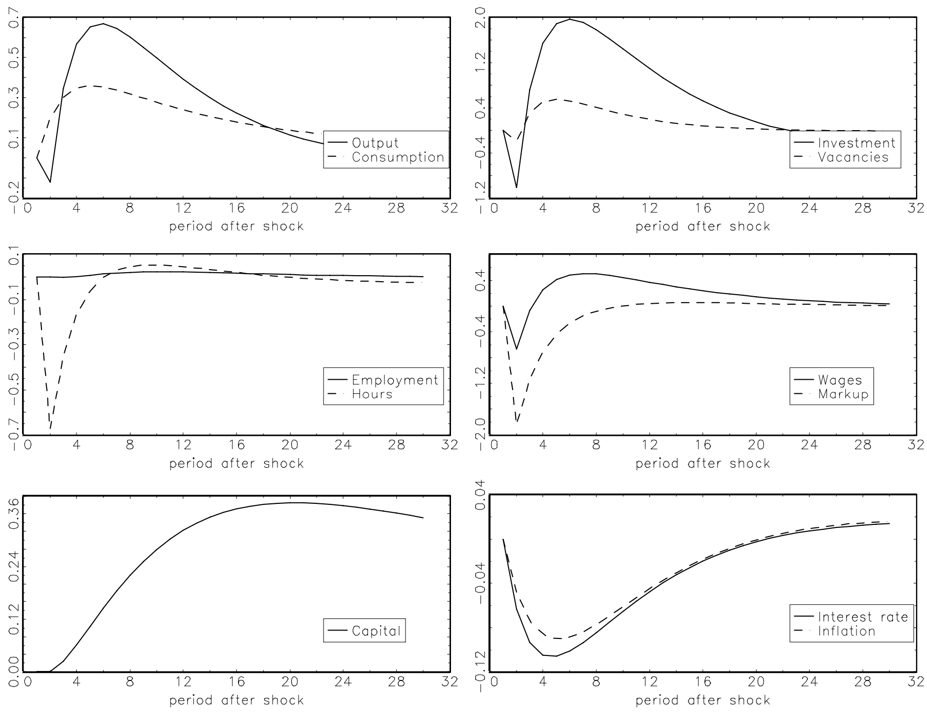

Figure 4: Responses to a technology shock

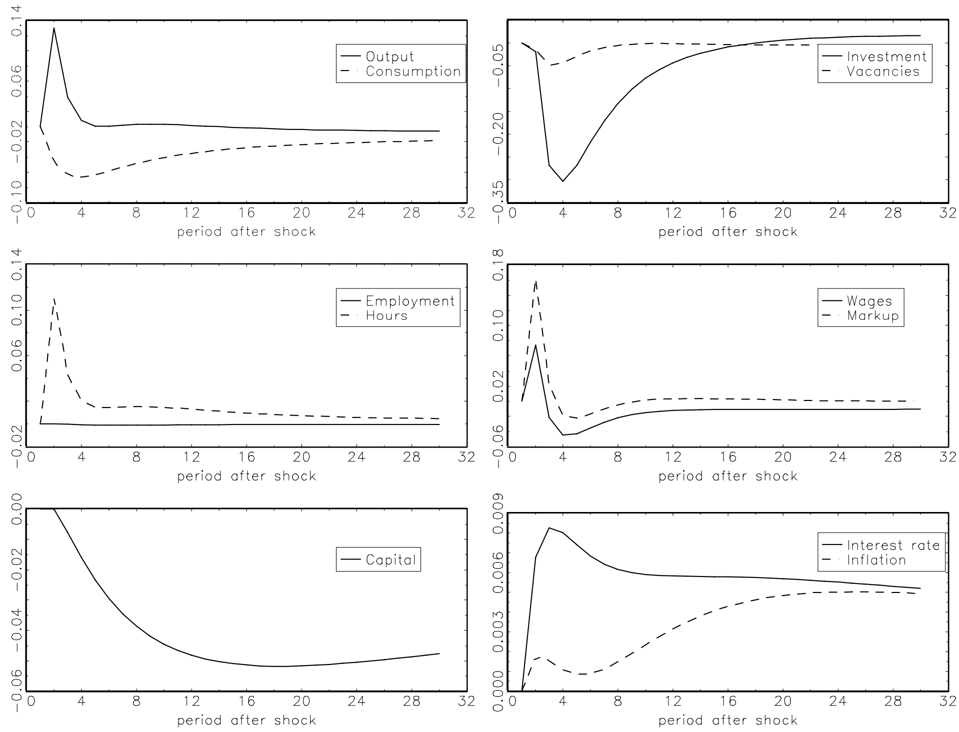

Figure 5: Responses to an expenditure shock

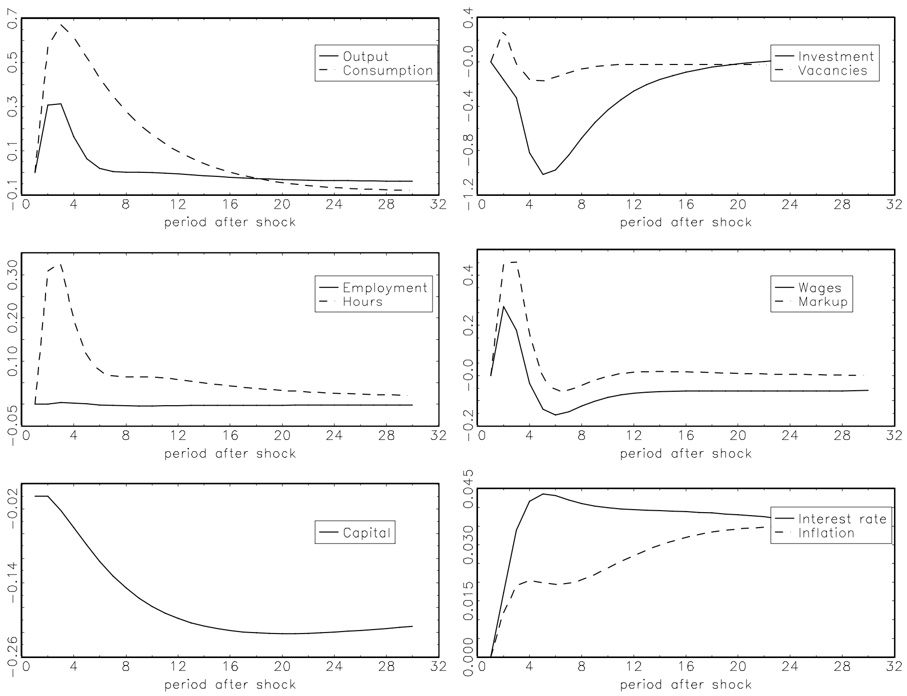

Figure 6: Responses to a preference shock

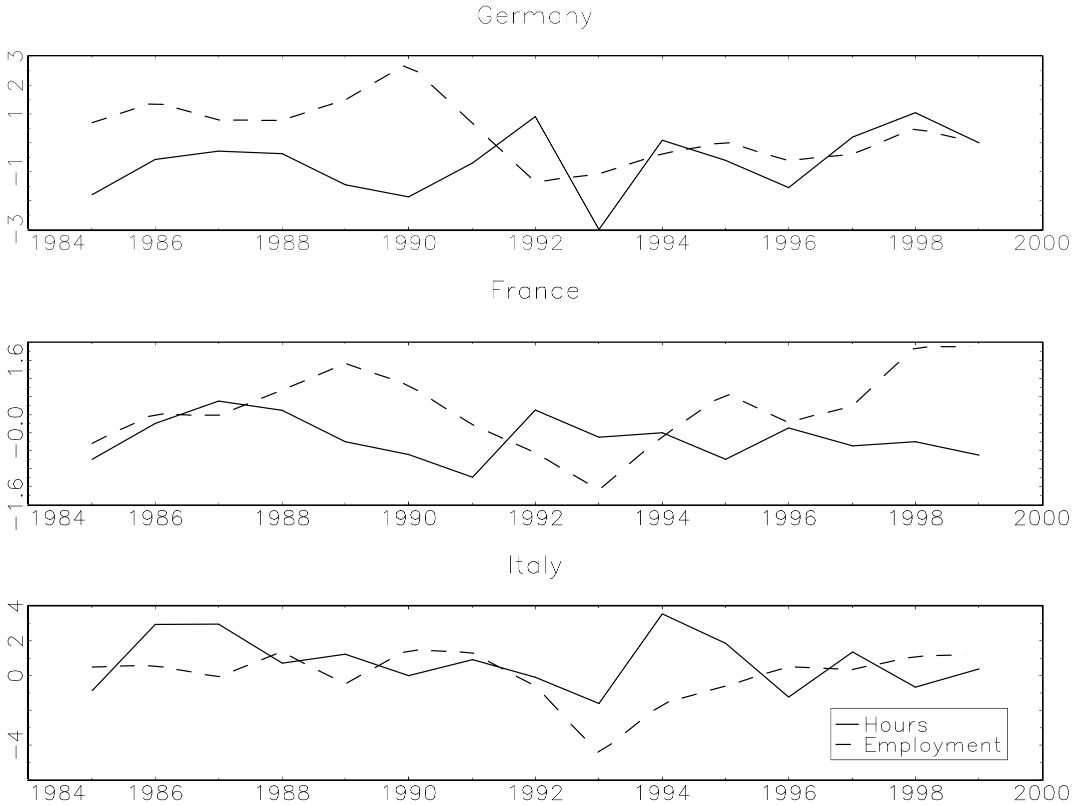

Figure 7: Annual growth rate of the hours worked and employment
<u>Source:</u> Bureau of Labour Statistics

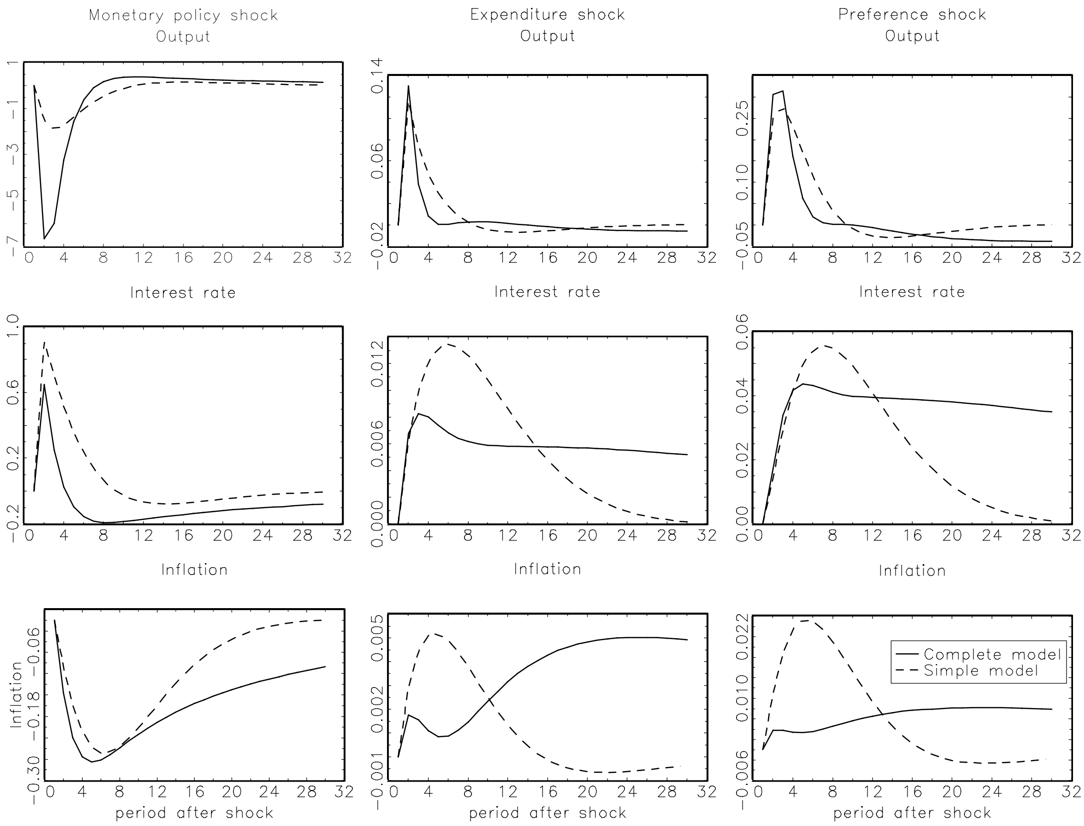

Figure 8: A comparison of impulse responses: simple vs. complete model

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