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

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Résumé :

Ce papier est consacré à la mesure des effets de l'introduction d'un marché du travail non Walrasien dans un modèle macroéconomique à anticipations rationnelles représentant la zone euro. Cette problématique s'inscrit dans les préoccupations récentes de la Banque Centrale Européenne qui cherche à appréhender toutes les caractéristiques de la zone. De ce fait, le cadre d'analyse original retenu permet d'étudier l'importance relative des rigidités liées au marché des biens et au marché du travail suite à des chocs de politique monétaire, technologiques et de dépenses publiques. Les conclusions marquantes de cette étude sont : (i) pour rendre compte des évolutions économiques, les rigidités réelles sont un complément nécessaire aux rigidités nominales mais ne les remplacent pas ; (ii) la dynamique des courbes de Phillips et de Beveridge est bien reproduite par le modèle ; (iii) les heures travaillées sont une variable d'ajustement cruciale ; et (iv) la dynamique des salaires réels reste procyclique.

Mots-clés : Modèles d'équilibre général intertemporels stochastiques, rigidités nominales, rigidités réelles, appariement sur le marché du travail, persistance endogène, zone euro.

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 in order to evaluate its ability to replicate the main features of the Euro area economy. This framework allows us to study the effects of labour market rigidities, nominal rigidities, and other frictions to give account of the impact of monetary policy, technology, public spending, and preference shocks. Our simulations show that: (i) real rigidities complement but do not supplant nominal rigidities, (ii) the Beveridge and Phillips relations are reproduced, (iii) hours worked are too sensitive an 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 classification: E32, C52, E24.

Résumé non technique :

Quels sont les effets de la présence de frictions du marché du travail sur la dynamique de l'économie et la propagation des chocs ? Bien que cette question soit centrale pour la macroéconomie et la politique économique, peu d'études ont cherché à y répondre dans un cadre d'équilibre général. Pourtant, les conséquences de telles frictions sur l'emploi, la production et l'inflation peuvent être considérées comme un problème non négligeable pour le banquier central en raison de ses implications sur la transmission de la politique monétaire.

En effet, comme l'explique une étude récente de la Banque Centrale Européenne (BCE, 2002), il y a coexistence d'un fort taux de chômage au sein de la zone euro (8,6 %) et d'un faible taux de participation (68,6 %). Cela signifie que les performances du marché du travail européen sont mauvaises. La compréhension du processus d'appariement entre offre et demande de travail apparaît ainsi comme une nécessité pour la prise de décision de politique monétaire : un étranglement sur le marché du travail peut créer des pressions inflationnistes ; de trop grandes différences de fonctionnement des marchés du travail entre les pays membres de la zone peuvent créer des effets asymétriques suite à un choc non anticipé.

Ainsi, moins de frictions sur le marché du travail de la zone euro devrait entraîner une réduction des effets de court terme de la politique monétaire sur l'économie réelle. L'objectif de cette étude est donc de prendre en compte ces rigidités au sein d'un modèle macroéconomique et d'en étudier les effets sur la dynamique de l'économie. Pour cela, nous construisons un modèle à anticipations rationnelles proche de celui présenté par la BCE (Smets et Wouters, 2003).

L'originalité de cette étude est l'introduction d'un marché du travail non Walrasien par le biais d'un processus permettant de prendre en compte l'existence de coûts de transaction sur le marché du travail et justifiant la coexistence d'emplois vacants et de chômeurs. En outre, la formation des salaires ne provient pas d'un processus concurrentiel abstrait, mais de négociations entre employeurs et travailleurs. L'architecture du modèle s'articule autour du concept de fonction d'appariement qui résume le processus de rencontre entre les personnes à la recherche d'un emploi et les entreprises disposant d'emplois vacants. Nous étalonnons le modèle sur la période 1985-2000 à l'aide des données disponibles à la BCE, puis après l'avoir résolu, nous comparons les résultats aux données afin que le modèle soit représentatif de la zone euro. Nous réalisons des simulations et observons les réponses du modèle suite à différents chocs individuels et temporaires : un choc de politique monétaire, un choc de dépenses publiques, un choc de productivité et un choc de préférence.

Le modèle reproduit une dynamique proche de celle de la zone euro et plus par-

ticulièrement celle provenant des courbes de Phillips (relation négative entre le taux de chômage et l'inflation) et de Beveridge (relation négative entre le taux de chômage et les emplois vacants). Alors que de nombreux économistes ont affirmé que les rigidités réelles devaient remplacer les rigidités nominales au sein d'un modèle macroéconomique, selon notre modèle les frictions sur le marché du travail ne sont pas un substitut mais un complément nécessaire aux rigidités nominales. Le modèle permet d'étudier les déterminants et l'évolution des marges intensives (les heures travaillées par employé) et extensives (le nombre d'employés) et met en avant le fait que les heures travaillées sont une variable trop centrale en ce sens que les firmes ajustent de manière peu "réaliste" cette dernière en réponse à des changements conjoncturels ou de leur structure de production. Afin de tenter de reporter les ajustements prononcés des heures travaillées sur le facteur capital, nous introduisons une variable d'utilisation du capital qui ne permet cependant de diminuer que faiblement le problème précédent. Tout comme dans le modèle de la BCE, il nous est impossible de trouver un degré "réaliste" de rigidité des prix. Nous mettons ainsi en évidence le fait que le banquier central devrait tenir compte des rigidités sur le marché du travail. Oublier ce degré supplémentaire de persistance pourrait l'amener à des décisions de politique monétaire erronées et à stabiliser l'économie moins efficacement.

Non-technical summary:

What are the effects of labour market frictions on the dynamics of the economy and the propagation of shocks? Even though such a question is central to macroeconomics and economic policy, very few studies sought to answer it in a general equilibrium framework. Yet the consequences of labour market rigidities on employment, output and inflation constitute an issue of great importance for both economists and policymakers.

As explained in a recent study on labour market mismatches provided by the european Central Bank (ECB, 2002), there is coexistence of a persistently high rate of unemployment (8.6%)and a low level of participation (68.6%). This suggests an insufficient ability of the euro area to match labour supply and demand. The understanding of labour market matching processes is of considerable importance for monetary policy. Firstly, bottlenecks in the labour market may trigger inflationary pressures. And secondly, differences in the labour market functioning and the impossibility to use country-specific monetary or exchange rate policies leads to asymmetrical effects following a symetric or asymetric shock.

Consequently, less friction on euro area labour market should reduce the short-run effects of monetary policy on the real economy. This paper addresses this issue by incorporating a non-Walrasian labour market instead of a nominal wage rigidity into the new generation of small-scale monetary business models called "New Neoclassical Synthesis" models. 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. Thus, our main objective is to evaluate the abilities of a dynamic stochastic general equilibrium model mixing sticky prices and labour market rigidities by accounting for the main features of the euro area, for all variables and for several structural shocks.

We show that the unconditionnal second moments generated by the calibrated model are close to those in the euro area during the period 1985-2000, except for the real wage dynamics, when both a high degree of nominal and labour market frictions are assumed. This indicates that labour market frictions do not act as a substitute for nominal rigidities but as a necessary complement. Thus, as in the model of the ECB, our model is not able to adress the shortcoming of requiring an implausible degree of price rigidity in order to match data. Since our modelling allows the possibility to investigate the theoretical determinants of the extensive and intensive margins on the labour market, we can see that hours per worker is too dominant as a leading indicator in the sense that their volatility is greater than that of employment. In response to a structural shock, hours per worker are the crucial variable of adjustment for firms. On this side, introducing a variable capital utilisation rate helps to solve part of this weakness since hours worked are no longer the only non-predetermined production factor. We show 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. Finally, the fact that a central banker which used a model without labour market rigidities would have all the chances to be mistaken in modifying their interest rate is bought to light.

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, p.1139)

1 Introduction

What are the effects of labour market frictions on the dynamics of the economy and the propagation of shocks? Even though such a question is central to macroeconomics and economic policy, very few studies sought to answer it in a general equilibrium framework.

Yet the consequences of labour market rigidities on employment, output and inflation constitute an issue of great importance for both economists and policymakers. As explained in a recent study on labour market mismatches 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 market 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 rate in the euro area is hardly cyclical, and that its dynamics is mainly explained by institutional and structural features. Unfortunately, such european labour market characteristics as the low mobility of 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).

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. Firstly, bottlenecks in the labour market may trigger inflationary pressures. And secondly, differences in the labour market functioning and the impossibility to use country-specific monetary or exchange rate policies leads to asymmetrical effects following a symetric or asymetric shock. Consequently, less friction on euro area labour market should reduce the short-run effects of monetary policy on the real economy. It is no longer possible to circumvent the modelling of labour market frictions in a macroeconomic model on which policy recommendations are to be based.

Although recent general equilibrium models focusing on the euro area economy, like Smets and Wouters (2002), are successful at explaining a number of phenomena, their lack of implications about the labour market and its effects on the overall economy is indeed a drawback.

This paper addresses this issue by incorporating a non-Walrasian labour market instead of a nominal wage rigidity into the new generation of small-scale monetary business models called "New Neoclassical Synthesis" models.[1] 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. Indeed, the literature on labour market search and real business cycles models has shown that such a mechanism generates realistic dynamics in employment and increases the magnitude and persistence of the impact of productivity shocks on output.[2] Thus, our main objective is to evaluate the abilities of a dynamic stochastic general equilibrium model mixing sticky prices and labour market rigidities by accounting for the main features of the euro area, for all variables and for several structural shocks.

In a recent work, Walsh (2003) incorporates a labour market matching process together with price stickiness in a cash-in-advance model and studies the implications for persistent output effects of monetary policy shocks on U.S. data. Within the euro area environment, we extend the scope of Walsh's paper in order to achieve results that are comparable to those derived by Smets and Wouters's (2003). First, we take into account both extensive and intensive margin on the labour market. Second, we introduce the main theoretical elements developed so as to reproduce the observed inertial dynamics of inflation and persistence in aggregate quantities. This includes habit formation in consumption behaviour, investment adjustment costs, and variable capital utilisation.

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. We explore the descriptive power of the simulated data and perform some simulations. Finally, section 4 concludes and gives directions for future research.

[1]See the seminal papers of Goodfriend and King (1997), Clarida et *al.* (1999) or Woodford (2003) for a presentation of the New Neoclassical Synthesis framework.

[2]The main contributions are Merz (1995), Andolfatto (1996), and den Haan, Ramey and Watson (2000).

2 The Model Economy

We consider a dynamic stochastic general equilibrium model along the lines of Christiano, Eichenbaum and Evans (2001), Neiss and Nelson (2002), and others. But our specification mainly departs from those papers with respect to the properties of the labour market.

We remove nominal wage rigidities and following Blanchard and Diamond (1989) and Pissarides (2000), the labour market specification is based on the economics of search. 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 as given.

Note also that we incorporate physical capital and investment based on the Q theory which makes it possible to model the fact that adjustment costs for capital and labour market frictions affect jointly firms' hiring.[3] Allowing for labour market search to interact with capital adjustment costs improves also the performance of investment dynamics and in turn output (Chéron and Langot, 1999, and Merz and Yashiv, 2003).

The economy consists of a government and numerous agents of three different types: households, wholesalers and retailers. Households choose consumption, bonds, and real-balances so as to maximise the present value of utility streams. As in Andolfatto (1996), it is assumed that there is an insurance market in the economy that unables agents to fully insure against idiosyncratic risks. This assumption makes households ex-ante identical and simplifies the analysis. The government consumes a share of final goods 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 input good and make investment and hiring decisions. Finally monopolistic retailers buy the input good to produce differenciated final goods sold to 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. It has preferences defined over a composite

[3] Authors generally make the nonrealistic but simplifying assumption that households make the capital accumulation and utilisation decisions.

consumption good (C_t), the 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 transaction-facilitating service. The representative household chooses a sequence of consumption (C_t), nominal money (Ξ_t) and one-period bonds (B_{t+1}), to maximise his lifetime utility:[4]

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^i \varepsilon_t^p \left[\frac{\sigma_c}{\sigma_c - 1} \left(C_{t+j} - \gamma \mathcal{H}_t\right)^{\frac{\sigma_c - 1}{\sigma_c}} - N_{t+j} \left(\frac{\sigma_n}{\sigma_n + 1} \left(H_{t+j}\right)^{\frac{\sigma_n + 1}{\sigma_n}} \right) + \frac{\sigma_m}{\sigma_m - 1} \left(\frac{\Xi_{t+j}}{P_{t+j}} \right)^{\frac{\sigma_m - 1}{\sigma_m}} \right] \tag{1}$$

subject to a series of real period budget constraints:

$$C_{t+j} + \frac{\Xi_{t+j}}{P_{t+j}} + \frac{B_{t+j+1}}{\left(1 + i_{t+j}\right) P_{t+j}} \leq W_{t+j} N_{t+j} H_{t+j} + \frac{B_{t+j}}{P_{t+j}} + \frac{\Xi_{t+j-1}}{P_{t+j}} - T_{t+j} + \Pi_{t+j} \tag{2}$$

where $\beta \in (0,1)$ represents the discount factor and ε_t^p is a general shock to preferences that affects the intertemporal substitution of households. It is asssumed to follow a first-order autoregressive process with i.i.d. Normal error term: $\ln(\varepsilon_t^p) = \left(1 - \rho_p\right) \ln\left(\bar{\varepsilon}^p\right) + \rho_p \ln(\varepsilon_{t-1}^p) + e_{1,t}$.

In equation (1), σ_c denotes 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 $\gamma \in [0,1)$ represents the habit formation parameter measuring the effect of stock on current utility. In this paper we work with strictly positive γ 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).[5] The habit stock is supposed to equal the level of aggregate consumption in the previous period, $\mathcal{H}_t = C_{t-1}$.

In equation (2), W_t denotes the hourly real wage, i_t denotes the nominal interest rate, T_t denotes the real lump-sum tax (government transfers) and Π_t is the sum of the dividends derived from retailers (Π_t^w) and wholesalers (Π_t^r).

[4] The perfect insurance system makes the representative household a weighted average of employed and unemployed households, where the weight is the employment rate. That's why the employment rate enters the utility function and the budget constraint. By simplification we suppose that there is no desutility to search a job.

[5] Fuhrer (2000) shows 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.

The consumption good C_t is a Dixit-Stiglitz aggregate of a multiplicity of differenciated goods, indexed by $z \in [0,1]$,

$$C_t = \left[\int_0^1 C_t(z)^{\frac{\epsilon-1}{\epsilon}} \mathrm{d}z \right]^{\frac{\epsilon}{\epsilon-1}} \tag{3}$$

where the parameter $\epsilon > 1$ is the elasticity of substitution between differenciated retail goods (or equivalently the price elasticity of demand). Given price $P_t(z)$ for the final goods, this preference specification implies the household's demand for good z is

$$C_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\epsilon} C_t \tag{4}$$

where the aggregate retail price index P_t is defined as

$$P_t = \left[\int_0^1 P_t(z)^{1-\epsilon} \mathrm{d}z \right]^{\frac{1}{1-\epsilon}}. \tag{5}$$

With λ_t the Lagrange multiplier on (2), the optimal household behaviour yields the following first-order conditions:

$$\lambda_t = \varepsilon_t^p \left(C_t - \gamma \mathcal{H}_t \right)^{-\frac{1}{\sigma_c}}, \tag{6}$$

$$\varepsilon_t^p \left(\frac{\Xi_t}{P_t} \right)^{-\frac{1}{\sigma_m}} = \lambda_t - \beta \mathbb{E}_t \frac{\lambda_{t+1} P_t}{P_{t+1}}, \tag{7}$$

$$\lambda_t = (1 + i_t) \beta \mathbb{E}_t \frac{\lambda_{t+1} P_t}{P_{t+1}}. \tag{8}$$

2.2 Labour Market Matching

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

$$N_{t+1} = (1-s) N_t + M_t \tag{9}$$

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 mass of recrutings at period t. Thus, matchings which take place at the period t are only productive at the following period.

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.[6] 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:

$$M_t = M(U_t, V_t) = \tilde{m} U_t^{\alpha} V_t^{1-\alpha} \tag{10}$$

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

The job vacancies and unemployed workers that are matched together in period t are randomly selected from the sets V_t and U_t. Hence, the stochastic process governing the state of vacant jobs during an interval of time is Poisson with rate

$$\tau_t = \frac{M(U_t, V_t)}{V_t}. \tag{11}$$

In other words, τ_t can be interpreted as the instantaneous probability of a vacancy being filled. Also, the average steady-state duration of a job vacancy is $1/\bar{\tau}$.

Similarly, the instantaneous probability that an unemployed worker finds a vacant position is given by:

$$\varrho_t = \frac{M(U_t, V_t)}{U_t} \tag{12}$$

which means that the average steady-state duration of unemployment is $1/\bar{\varrho}$.

2.3 Wholesalers

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

$$\begin{aligned} X_t^w &= f(\varkappa_t K_t, N_t H_t) \\ &= \varepsilon_t^a (\varkappa_t K_t)^{\eta} (N_t H_t)^{1-\eta} \end{aligned} \tag{13}$$

where $\eta \in (0,1)$, $\varkappa_t$ is the capital 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: $\ln(\varepsilon_t^a) = (1-\rho_a)\ln(\bar{\varepsilon}^a) + \rho_a \ln(\varepsilon_{t-1}^a) + e_{2,t}$.

[6] 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 people are engaged in search. This assumption implies that the two activities of production of goods and trade in labour market are strictly separate activities.

The modellisation of investment can be linked to Tobin's Q-model, which couples investment decisions to forward-looking stock market valuations of the firm.[7] 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 too fast an accumulation of capital is more costly.

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

$$K_{t+1} = \left(1 - \delta\left(\varkappa_t\right)\right) K_t + I_t \tag{14}$$

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

$$\delta\left(\varkappa_t\right) = \tilde{\delta}\frac{\varkappa_t^d}{d} \tag{15}$$

that reflects the fact that a higher utilisation rate raises the depreciation rate of capital (King and Rebelo, 1999). $\tilde{\delta} > 0$ is a scale parameter.

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

$$A\left(I_t, K_t, \varkappa_t\right) = \frac{\Theta}{2}\left(\frac{I_t}{K_t} - \delta\left(\varkappa_t\right)\right)^2 K_t \tag{16}$$

with $\Theta > 0$.

The representative firm chooses sequences of vacancies, investment, and utilisation rate in order to maximise the expected sum of discounted profits, taking as given a per vacancy cost (ς):

$$\begin{aligned} \max_{\{V_{t+j}, I_{t+j}, \varkappa_{t+j}\}} \mathbb{E}_t \Bigg\{ \sum_{j=0}^{\infty} \beta^j \frac{\lambda_{t+j}}{\lambda_t} & \left[\Upsilon_{t+j} f\left(\varkappa_{t+j} K_{t+j}, N_{t+j} H_{t+j}\right)\right. \\ & \left. - W_{t+j} N_{t+j} H_{t+j} - \varsigma V_{t+j} - \left(I_{t+j} + A\left(I_{t+j}, K_{t+j}, \varkappa_{t+j}\right)\right)\right]\Bigg\} \end{aligned} \tag{17}$$

subject to the following constraints:

$$N_{t+j+1} = \left(1 - s\right) N_{t+j} + \tau_{t+j} V_{t+j}, \tag{18}$$

$$K_{t+j+1} = \left(1 - \delta\left(\varkappa_{t+j}\right)\right) K_{t+j} + I_{t+j}. \tag{19}$$

The first-order conditions of this program are given by:

[7] See Gertler and Gilchrist (2000) for an appraisal of the macroeconomic consequences of investment delays in a staggered-prices framework.

$$\frac{\varsigma}{\tau_t} = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\Upsilon_{t+1} f'_{N_{t+1}} - W_{t+1} H_{t+1} + (1-s) \frac{\varsigma}{\tau_{t+1}} \right) \right], \tag{20}$$

$$1 + A'_{I_t} = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\Upsilon_{t+1} f'_{K_{t+1}} - A'_{K_{t+1}} + (1-\delta) \left(1 + A'_{I_{t+1}} \right) \right) \right], \tag{21}$$

$$\Upsilon_t f'_{\varkappa_t} = K_t \delta'_{\varkappa_t}. \tag{22}$$

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 generated by a successful match between an unemployed worker and a vacant job is the marginal value of employment. One can show (see Appendix A for details) that hourly real wage and hours worked are given by:

$$W_t = \xi \left((1-\eta) \frac{\Upsilon_t Y_t}{N_t H_t} + \frac{\varsigma}{H_t} \frac{V_t}{U_t} \right) + (1-\xi) \left(\varepsilon_t^p \frac{\sigma_n (H_t)^{\frac{1}{\sigma_n}}}{(\sigma_n + 1) \lambda_t} \right), \tag{23}$$

$$(1-\eta)^2 \frac{\Upsilon_t Y_t}{N_t H_t} = \varepsilon_t^p \frac{H_t^{\frac{1}{\sigma_n}}}{\lambda_t} \tag{24}$$

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 a differenciated final good $Y_t(z)$ with a technology that transforms one unit of wholesale goods into one unit of retail goods, so that $Y_t(z) = X_t^w(z)$. Firms on the retail sector purchase output from wholesale producers at the price Υ_t (which becomes the firm's real marginal cost) and directly sell to households.

For the sake of simplicity, we assume that the government and the wholesaler have the same optimal intratemporal allocations for each differenciated goods as the household. This implies that the demand curve facing each retailer is given by:

$$Y_t(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\epsilon} Y_t. \tag{25}$$

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 adjustment costs. In particular, the economy-wide resource constraint is given by:

$$Y_t = C_t + I_t + G_t + \varsigma V_t + A_t. \tag{26}$$

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 elapsed time since they revised their prices. These drawings are independant of history and we do not need to keep track of firms changing prices. The expected time over which the price is fixed, i.e. the expected waiting time until the next price adjustment, is therefore $\frac{1}{1-\phi}$. The remaining fraction ϕ of firms that are assumed to adjust their previous period's prices follows the simple rule:

$$P_t(z) = \pi_{t-1} P_{t-1}(z). \tag{27}$$

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

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

$$\mathbb{E}_t \sum_{j=0}^{\infty} (\phi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} \left[\frac{P_t^*(z)}{P_{t+j}} - \Upsilon_{t+j}\right] Y_{t+j}(z) \tag{28}$$

subject to the demand curve (25).

$\beta^j \frac{\lambda_{t+j}}{\lambda_t}$ 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 maximisation of (28) is given by:

$$P_t^*(z) = \frac{\epsilon}{\epsilon - 1} \frac{\mathbb{E}_t \sum_{j=0}^{\infty} (\phi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} P_{t+j}^{\epsilon} Y_{t+j} \Upsilon_{t+j}}{\mathbb{E}_t \sum_{j=0}^{\infty} (\phi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} P_{t+j}^{\epsilon-1} Y_{t+j}} \tag{29}$$

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

Finally, since there is no firm-specific factors influencing pricing decisions, the fraction $(1-\phi)$ of the retailers that adjust in t chooses the same new price P_t^* and the same level of output, and the average price of firms that do not adjust is simply last period's price level scaled by last period's inflation $(\pi_{t-1}P_{t-1})$. The dynamics of the consumption-based price index is then,[8]

$$P_t = \left[\phi\left(\pi_{t-1}P_{t-1}\right)^{1-\epsilon} + (1-\phi)\, P_t^{*1-\epsilon}\right]^{\frac{1}{1-\epsilon}}. \tag{30}$$

2.6 Fiscal and Monetary Policy

We now close the model by specifying the government's behaviour. The government conducts both fiscal and monetary policies. We assume that exogeneous government expenditure (G_t) are financed by lump-sum taxation, as well as money and bonds creation. Since we do not consider distortionary taxes, the government faces the following budget constraint:

$$G_t = \frac{\Xi_t - \Xi_{t-1}}{P_t} + \frac{B_{t+1}/\left(1+i_t\right) - B_t}{P_t} + T_t \tag{31}$$

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 instrument privileged by monetary authority. The monetary authority adopts a feedback rule that has the nominal rate adjust to deviations of economy-wide inflation from its steady state value and output from its natural value, i.e. the equilibrium level of output under complete price flexibility (Y_t^n). 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

$$(1+i_t) = (1+i_{t-1})^{\psi_i}\left[\left(\frac{P_t}{P_{t-1}}\right)^{\psi_\pi}\left(\frac{Y_t}{Y_t^n}\right)^{\psi_y}\right]^{1-\psi_i}\exp\left(\varepsilon_t^i\right) \tag{32}$$

where ε_t^i is an i.i.d monetary policy shock, 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 (7)), given the choice of i_t;

[8] See Yun (1996) or Woodford (2003).

- in equilibrium the excess of supply of bonds must be zero: $B_t = 0$.

3 Quantitative Evaluation

The main 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 the assumed degree of rigidities. We present our choice of calibration and the comparisons between models and their empirical counterparts using the unconditional second moments. Finally, the impulse response functions of the selected model are computed. They show the transmission mechanisms of the structural shocks and illustrate the dynamic properties of the general model.

3.1 Solution and Model Parameterisation

In order to get the model in a tractable form for conducting policy simulations we need to look for an approximate analytical solution by transforming 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. The resulting system, expressed in terms of percentage deviations around the steady-state is presented in Appendix B.

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).

The parameter values are pinned down so that the euro area model economy fluctuates around its stationary state over the period 1985-2000. The choice of the period of calibration answers a twofold aim: appointing the longest period while avoiding too significant breaks.[9] The euro area data retained for the calibration

[9] Calibration is used instead of estimation for two reasons. First, European data pertaining to the labour market are seldom complete (e.g. hours worked and vacancies are usually not available). Estimating the model with such an incomplete dataset would induce a level of parameter uncertainty that goes beyond the acceptable limits. Second, since the euro area was created only recently, its behaviour can be inferred from its past rather than directly estimated from the previous joint

result from the "augmented" database used by Fagan, Henry and Mestre (2001) for the Area Wide Model of the ECB. 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 to those estimated by Smets and Wouters (2003). Sahuc (2002) or Smets and Wouters (2003) considered values of γ ranging from 0.57 to 0.96. Here, we retain an intermediate value of 0.75.

Concerning the matching process and the labour market, we follow Petrongolo and Pissarides (2001) survey of empirical studies for the Cobb-Douglas matching function parameter and set $\alpha = 0.5$. The relative bargaining power of workers is set to $\xi = 0.5$ so that employers and workers have the same bargaining strength. According to the euro area data, the NAIRU is estimated at 8.6% which implies a value for $\bar{N}$ of 0.914. The steady-state value of the separation rate is given by $s = \left(\bar{\varrho}\bar{U}\right) / \left(1 - \bar{U}\right)$.

According to the AWM database, the share of government spending in the GDP $\left(\bar{G}/\bar{Y}\right)$ is equal to 16.22% and the share of consumption in GDP $\left(\bar{C}/\bar{Y}\right)$ is 62.56%. The rate of capital depreciation is set at 2% in order to make the share of investment relative to GDP $\left(\bar{I}/\bar{Y} = 20.22\%\right)$ compatible with the coefficient of capital $\left(\bar{K}/\bar{Y} = 9.68\right)$. The capital share parameter was obtained by estimating a production function by OLS. The estimated parameter could not reject $\eta = 0.35$. Moreover, guided by the empirical work of Basu and Kimball (1997), we set the elasticity of marginal depreciation with respect to the utilisation rate (d) to unity.

The reaction function of the monetary authority is assumed to be an inertial Taylor rule with the 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 steady-state probabilities $\bar{\tau}$ and $\bar{\varrho}$, are more difficult to gauge. They will be taken as free parameters and we will use the cross-correlations to assess plausible values.

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

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behaviour of its members. Moreover, the problems of aggregation and the entry of new members make the quality of the data debatable and require additional adjustments.

3.2 Unconditional Second Moments

An informal assessment of the quantitative performance of the model and dynamic propagation 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 computed 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. Specification 1: $\phi = 0.75$ (prices are fixed for one year), $\bar{\varrho} = 0.5$ (the duration of unemployment is 6 months) and $\bar{\tau} = 0.95$ (the duration of vacancies is three months);

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

3. Specification 3: $\phi = 0.9$ (prices are fixed for two years and a half), $\bar{\varrho} = 0.5$ (the duration of unemployment is 6 months) and $\bar{\tau} = 0.95$ (the duration of vacancies is three months);

4. Specification 4: $\phi = 0.9$ (prices are fixed for two years and a half), $\bar{\varrho} = 0.25$ (the duration of unemployment is 12 months) and $\bar{\tau} = 0.5$ (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 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 relied on a very high degree of price rigidity ($\phi = 0.9$) in order to match the data. One important reason for the relatively high degree of nominal stickiness in prices comes from the fact that the sensitivity of marginal cost to output is closely related to a firm's ability to adjust its input. In our model, the two non-predetermined variables (capital utilisation rate and hours per worker) introduce additional margin by which firms can respond to unanticipated shocks, reducing the effect of output on marginal cost. In other words, capital utilisation rate and hours per worker result in a flattening of the marginal cost schedule thereby introducing the possibility of endogenous price stickiness (effect reinforced by the assumption of constant returns to scale in the production function). On the other hand, standard sticky-price models with capital are subject to increasing short-run marginal costs, which in turn dampens the response of output. The real effect of shocks on output in such models is consequently weak, and can only be accomplished by assuming a relatively high degree of nominal rigidity.

In addition, when we introduce high durations of unemployment and vacancies (specification 4), the lag and lead cross correlations for almost all the variables in the model are quite close to those of the data, both in sign and magnitude. For example, we can observe that consumption, investment, and employment are strongly procyclical while capital or interest rates are acyclical. The model performs reasonably well with respect to unemployment.

Correlations between unemployment and output are generally countercyclical as reflected by the data and the negative correlation between inflation and unemployment describes 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 monetary policy. Thus, a model aiming at informing the monetary policy debate, such as ours, must qualitatively account for the Phillips-curve.

Although we do not have a series of vacancies, Chart 2 of the ECB document (2002, p.17) allows us to say that euro area data display a strong negative correlation between vacancies and unemployment.[10] 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.

However, the most serious weakness of the model with staggered price and labour market search is its inability to generate the correct dynamic pattern for real wages.[11] Contemporaneously, one can see that we face the usual difficulty of labour market search model to account for the low procyclicity of real wages. By adding exter-

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

[11] Shimer (2003) argued that a search and matching model in which wages are determined by Nash bargaining cannot generate substantial movements along a downward sloping Beveridge curve in response to shocks.

nal habit on consumption we have expected that persistent consumption movement will make the marginal desutility of work (in terms of consumption) and thus real wages less procyclical. Unfortunately, wages are still too procyclical. The divergence between data and the model suggests that future work could focus on modifying the wage equation. A mean is to make it partially backward-looking or, as shown in Chéron and Langot (2002), allowing for non separable preferences beetween consumption and leisure.

Finally, one can calculate a simple measure to evaluate the fit of a dynamic structural economic model in using a modified root mean squared error criteria for the cross-correlations (called RMSECC). It is defined as the root of the sum of the squared of the difference between data and model cross-correlations:

$$RMSECC = \left(\sqrt{\frac{1}{\Lambda} \sum_{o=1}^{O} \sum_{l=-8}^{8} \left[Corr\left(x_{k,t}^{obs}, x_{k,t+l}^{obs}\right) - Corr\left(x_{k,t}^{sim}, x_{k,t+l}^{sim}\right) \right]^2} \right)$$

where $x_t^{state} = \{y_t^{state}, c_t^{state}, \pi_t^{state}, I_t^{state}, n_t^{state}, u_t^{state}, i_t^{state}, w_t^{state}, k_t^{state}\}$ is a vector of observable $(state = obs)$ or simulated $(state = sim)$ variables, O is the number of variables in x_t, l is the number of lags and leads of the cross-correlations, and Λ is a scale parameter. Table 2 provides a summary of the RMSECC for the four specifications. In just the same way as shown graphically, it is noticed that the increase in the degree of real rigidities makes it possible to decrease the differences between observed and simulated autocorrelations approximately 5% (mainly the correlations related to the labour market) and that the increase in the degree of nominal rigidity decreases them by 15%. This confirms the crucial aspect of the degree of price rigidity and the complementarity of the rigidity on labour market.

We maintain the specification 4 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 underlying model shocks. The impulse reponses are depicted in Figures 2 through 5. 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 both the Phillips curve and the Beveridge curve.

3.3.1 Monetary Policy Shock

Figure 2 reports the responses to an increase in the nominal interest rate. This shock is a perturbation of the monetary policy rule and therefore, it triggers the implied correction mechanisms.

Following this shock, households reduce their consumer spending (-1%) as the real interest rate increases (0.6%). Firms respond to the hike in interest rate by sharply reducing their investment spending (-18%) and decreasing hours per worker (-2.2%) 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 investment is stronger than that in consumption. Inflation decreases slowly due to price rigidities.

Since vacancies reflect recruiting efforts and move in response to the expectation of the profitability of a successful match, they drop (-8%) following the decrease in the marginal cost (-5.5%). However, we can notice that this variable is the first to start its final hump shape pattern. The fall in employment (-0.3%) 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 (-7.5%) 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_tH_t) via hours per worker (the intensive margin). Although this effect is too important in our study and contrary to what many people say, it is not disconnected from reality. As Figure 6 for the three larger countries of the euro area shows it, the evolution of the annual growth rate of hours worked is as volatile as that of employment.[12]

3.3.2 Technology Shock

Figure 3 shows the effects of an improvement in total factor productivity. The output response is automatically and quickly positive and keeps building up gradually

[12] 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.

(0.85%). The shock raises consumption (0.5%) since households increase their spending. Their real wages are indexed to productivity and increased gradually but significantly (1%). As noted before, they follow furthermore the vacancies-unemployment ratio, thus confirming 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 (-0.03%) and exhibits persistence). Investment and vacancies also rise by 2.3% and 1%, respectively.

Two features must be noted concerning the employment dynamics. First, 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 (-0.5%)) given the increase in productivity. Our model is then consistent with the findings of Gali (1999) on OECD countries and Smets and Wouters (2003) on euro area data. Contrary to the Dotsey's (2002) claim, one can produce a negative correlation between productivity and total hours in the presence of an interest rate rule and sticky prices. Second, contrary to the evidence, firms mainly adjust total hours *via* individual hours and not *via* employment.

3.3.3 Shock to Government Spending

Figure 4 plots the dynamic responses of selected variables to a shock to government consumption. Such a shock always raises 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 (-0.06%) though 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 an excess demand in the goods market at the prevailing interest rate, and the interest rate must go up to clear the goods market (0.012%). Then, capital stock and investment fall (-0.04% and –0.22%, 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 are the real interest rate and the global surplus in each period. We observe that even though the global surplus increases in response 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 (-0.08%) just like the employment (-0.005%).

3.3.4 Preference Shock

Figure 5 reports the responses to a preference shock. The shock acts directly on consumption by increasing it by 0.26% and makes it possible to increase output by 0.18%. We notice that the preference shock has a stronger impact on output than the government spending shock.

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, the real interest rate rises inducing a significant negative crowding-out effect on investment (–0.55%). The increase in capacity necessary to match the increased demand derives from a rise 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 (0.04%) and in employment (0.01%) as several VAR models suggest it in the literature.

3.4 Some Lessons for Monetary Policy

Before concluding, we have to clarify two important points for the monetary policy decisions.

First, since the introduction of labour market frictions has a strong impact on the overall dynamics of the model, the policy recommendations can vary a great deal according to whether a model without labour market rigidities or a more complete one is used as a policy guide. The previous study of the cross-correlations and the response functions has allowed to demonstrate that the introduction of frictions other than those on the market of goods exacerbates the endogenous persistence. Consequently, the monetary authorities which used a model without labour market rigidities would have all the chances to be mistaken in modifying their interest rate. The stabilisation of the economy would be much longer than than they hoped.

Second, the comparison of several monetary policy rules gives some interesting results. We are interested in comparing three rules: (1) an inflation targeting rule, (2) the Taylor-type rule retained until now, and (3) an augmented Taylor-type rule:

$$\begin{array}{llcl}
(1) & i_t & = & \psi_i i_{t-1} + (1-\psi_i)\left[\psi_\pi \pi_t\right] + \varepsilon_t^i \\
(2) & i_t & = & \psi_i i_{t-1} + (1-\psi_i)\left[\psi_\pi \pi_t + \psi_y \left(y_t - y_t^n\right)\right] + \varepsilon_t^i \\
(3) & i_t & = & \psi_i i_{t-1} + (1-\psi_i)\left[\psi_\pi \pi_t + \psi_y \left(y_t - y_t^n\right) + \psi_u \left(u_t - u_t^n\right)\right] + \varepsilon_t^i
\end{array}$$

Figure 7 shows the responses of output, inflation, employment and interest rate following the two economic policy shocks. The dashed lines responses are those of the model including an inflation targeting rule, the solid lines are those of our model, and the dotted line are those of the model including the unemployment-augmented Taylor-type rule.

One can highlight the fact that an inflation targeting rule gives worse results in terms of stabilisation than a Taylor-type rule. This is not a new result since it is obvious that adding additionnal variables in a rule allows improved stabilising properties. However, as shown in Figure 8, to put a more important weight on the output gives better results (see for example the rule estimated by Sahuc, 2002). Moreover, as in the case when it comes from to the financial market, one may wonder whether the monetary authorities should include a labour market slack variable, such as the unemployment rate, in their monetary policy rule. Our simulations suggest that the introduction of the unemployment rate in the rule (with the same weight as the output for example) slightly helps to achieve faster inflation stabilisation 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 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 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 for the real wage dynamics, when both a high degree of nominal and labour market frictions are assumed. This indicates that labour market frictions do not act as a substitute for nominal rigidities but as a necessary complement. Thus, as in Smets and Wouters (2003), 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 paper, our model allows the possibility to investigate the theoretical determinants of the extensive and intensive margins on the labour market. Unfortunately, we are not able to match the usual empirical VAR responses of individual hours worked relative to employment. Indeed, we find that hours per worker is *too dominant* as a leading indicator in the sense that their volatility is greater than that of employment. In response to a structural shock, hours per worker are the crucial variable of adjustment for firms. On this side, introducing a variable capital utilisation rate helps to solve 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.

Appendix A: 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:

$$\begin{aligned}\frac{\partial\Omega_t^F}{\partial N_t} &= (1-\eta)\frac{\Upsilon_t Y_t}{N_t} - W_t H_t + \beta\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial N_{t+1}}{\partial N_t}\frac{\partial\Omega_{t+1}^F}{\partial N_{t+1}} \\ &= (1-\eta)\frac{\Upsilon_t Y_t}{N_t} - W_t H_t + \beta\frac{\lambda_{t+1}}{\lambda_t}(1-s)\frac{\partial\Omega_{t+1}^F}{\partial N_{t+1}} \\ &= (1-\eta)\frac{\Upsilon_t Y_t}{N_t} - W_t H_t + \frac{\varsigma}{\tau_t}(1-s) \qquad (33)\end{aligned}$$

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:

$$\begin{aligned}\frac{\partial\Omega_t^H}{\partial N_t} &= \lambda_t W_t H_t - \varepsilon_t^p\frac{\sigma_n}{\sigma_n+1}(H_t)^{\frac{\sigma_n+1}{\sigma_n}} + \beta\frac{\partial N_{t+1}}{\partial N_t}\frac{\partial\Omega_{t+1}^H}{\partial N_{t+1}} \\ &= \lambda_t W_t H_t - \varepsilon_t^p\frac{\sigma_n}{\sigma_n+1}(H_t)^{\frac{\sigma_n+1}{\sigma_n}} + \beta(1-s-\varrho_t)\frac{\partial\Omega_{t+1}^H}{\partial N_{t+1}} \qquad (34)\end{aligned}$$

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. The real wage is then determined according to the maximisation 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:

$$W_t = \arg\max_{\{W_t\}}\left(\frac{\partial\Omega_t^H}{\lambda_t\partial N_t}\right)^{\xi}\left(\frac{\partial\Omega_t^F}{\partial N_t}\right)^{(1-\xi)} \qquad (35)$$

The first order condition gives the following surplus sharing rule:

$$\xi\frac{\partial\Omega_t^F}{\partial N_t} = (1-\xi)\frac{\partial\Omega_t^H}{\lambda_t\partial N_t} \qquad (36)$$

Iterating (36) one period in the future and multiplying by $\frac{\beta}{\lambda_t}$ we obtain:

$$\xi\beta E_t\left(\frac{\lambda_{t+1}\partial\Omega_{t+1}^F}{\lambda_t\partial N_{t+1}}\right) = (1-\xi)\beta E_t\left(\frac{\partial\Omega_{t+1}^H}{\lambda_t\partial N_{t+1}}\right) \qquad (37)$$

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:

$$\frac{\varsigma}{\tau_t} = \frac{(1-\xi)}{\xi}\beta\frac{\partial\Omega_{t+1}^H}{\lambda_t\partial N_{t+1}} \qquad (38)$$

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

$$W_t = \xi \left((1-\eta) \frac{\Upsilon_t Y_t}{N_t H_t} + \frac{\varsigma}{H_t} \frac{V_t}{U_t} \right) + (1-\xi) \left(\varepsilon_t^p \frac{\sigma_n (H_t)^{\frac{1}{\sigma_n}}}{(\sigma_n + 1) \lambda_t} \right) \tag{39}$$

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

$$S_t = \frac{\partial \Omega_t^H}{\lambda_t \partial N_t} + \frac{\partial \Omega_t^F}{\partial N_t} \tag{40}$$

so the first order condition is

$$\frac{\partial S_t}{\partial H_t} = (1-\eta)^2 \frac{\Upsilon_t Y_t}{N_t H_t} - \frac{\varepsilon_t^p}{\lambda_t} \frac{\partial \left[\frac{\sigma_n}{\sigma_n + 1} (H_t)^{\frac{\sigma_n + 1}{\sigma_n}} \right]}{\partial H_t} = 0 \tag{41}$$

Finally, we obtain:

$$(1-\eta)^2 \frac{\Upsilon_t Y_t}{N_t H_t} = \varepsilon_t^p \frac{H_t^{\frac{1}{\sigma_n}}}{\lambda_t} \tag{42}$$

Appendix B: The Log-Linearised Model

- Consumption

$$\hat{c}_t = \gamma \hat{c}_{t-1} + \left[(1-\gamma)\,\sigma_c\right]\left(\hat{\varepsilon}_t^p - \hat{\lambda}_t\right)$$

- Euler equation

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

- Inflation

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

- Hours

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

- Capital accumulation

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

- Aggregate constraint

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

- Investment

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

- Employment

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

- Marginal costs

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

- Job vacancies

$$\begin{aligned}\hat{v}_t \quad = \quad & \hat{m}_t + \frac{\beta\bar{\tau}\,(1-\eta)\,\bar{\Upsilon}\bar{Y}}{\varsigma\bar{N}}\left(\mathbb{E}_t\hat{\Upsilon}_{t+1} + \mathbb{E}_t\hat{y}_{t+1} - \mathbb{E}_t\hat{n}_{t+1}\right) + \mathbb{E}_t\hat{\lambda}_{t+1} - \hat{\lambda}_t \\ & +\beta(1-s)\left(\mathbb{E}_t\hat{v}_{t+1} - \mathbb{E}_t\hat{m}_{t+1}\right) - \frac{\beta\bar{\tau}\bar{W}\bar{H}}{\varsigma}\left(\mathbb{E}_t\hat{w}_{t+1} + \mathbb{E}_t\hat{h}_{t+1}\right)\end{aligned}$$

- Capacity utilisation

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

- Unemployment

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

- Wages

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

- Government spending

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

- Interest rate rule

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

- 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

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

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Table 1
Euro area model calibration

Description	Parameter	Quarterly Value
Intertemporal elasticity of substitution	σ_c	0.740
Elasticity of work effort	σ_n	0.420
Discount factor	β	0.990
Habit formation parameter	γ	0.750
Probability of not resetting 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
Lagged 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 2
The RMSECC criteria

Model	Mean	Variance	Gain
Specification 1 (benchmark)	10.904	4.842	-
Specification 2	10.382	4.708	5.028%
Specification 3	9.417	2.206	15.791%
Specification 4	9.230	1.742	18.137%

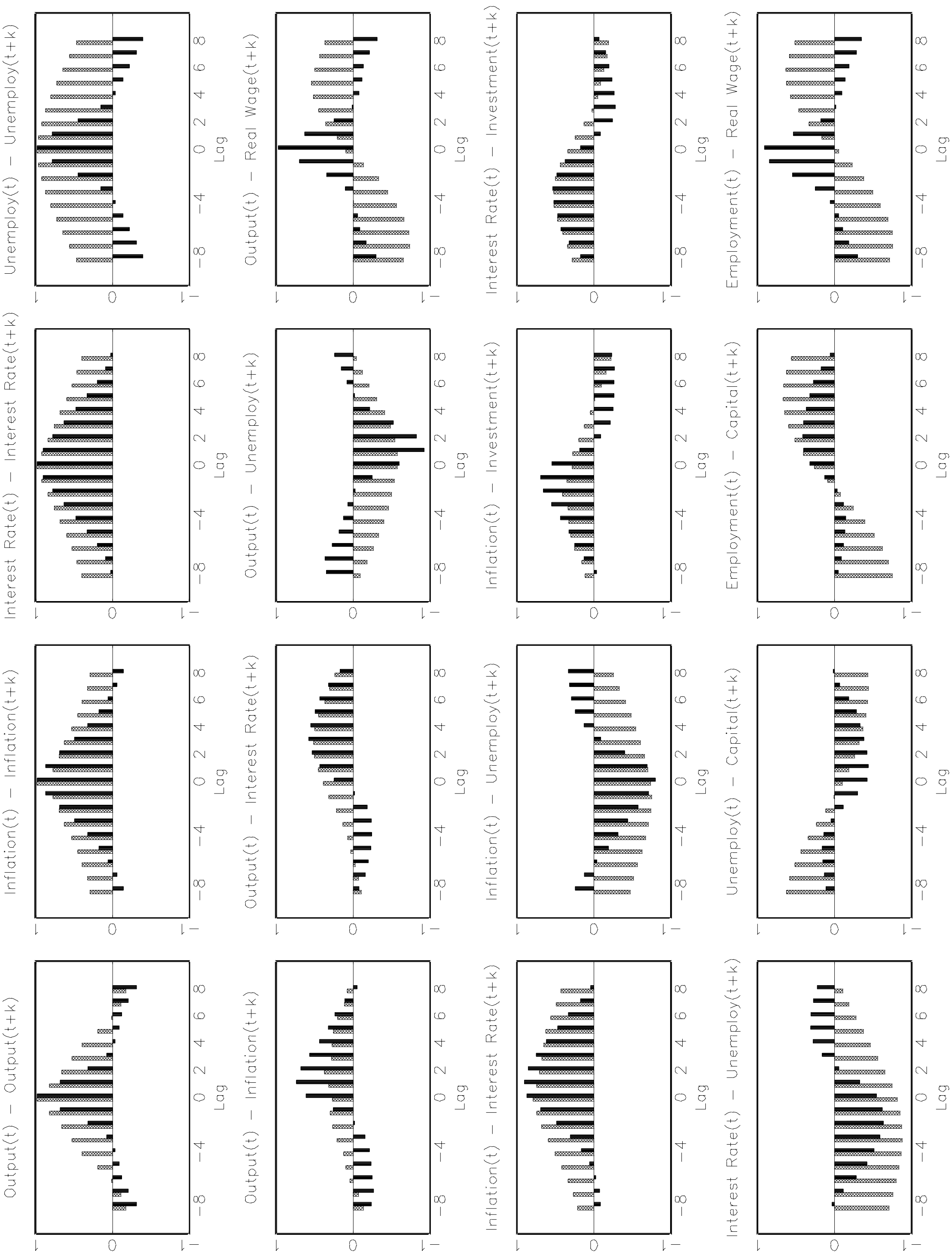

Fig. 1a. Comparison of cross correlations of the DSGE model and the data. (Specification 1).

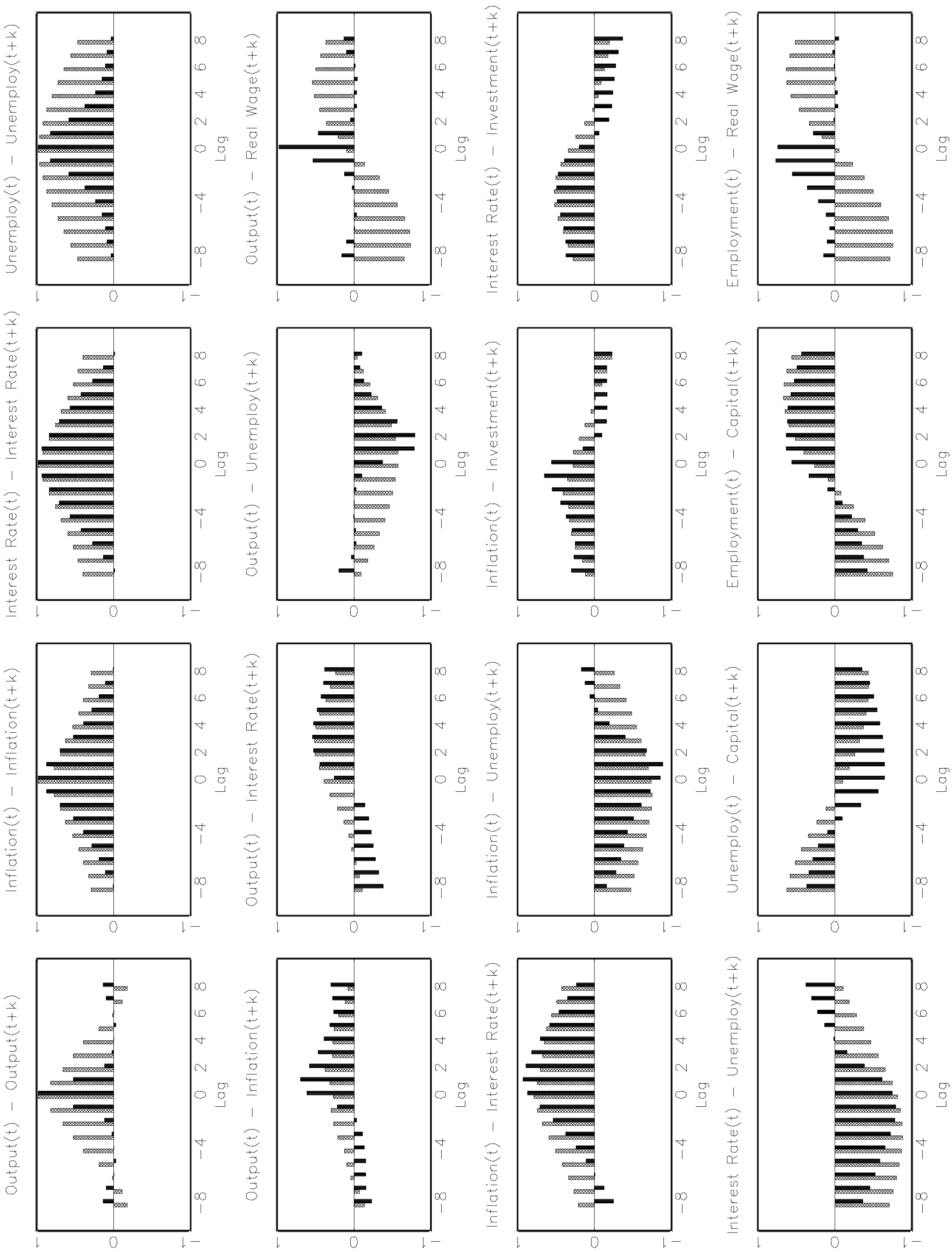

Fig. 1b. Comparison of cross correlations of the DSGE model and the data. (Specification 2).

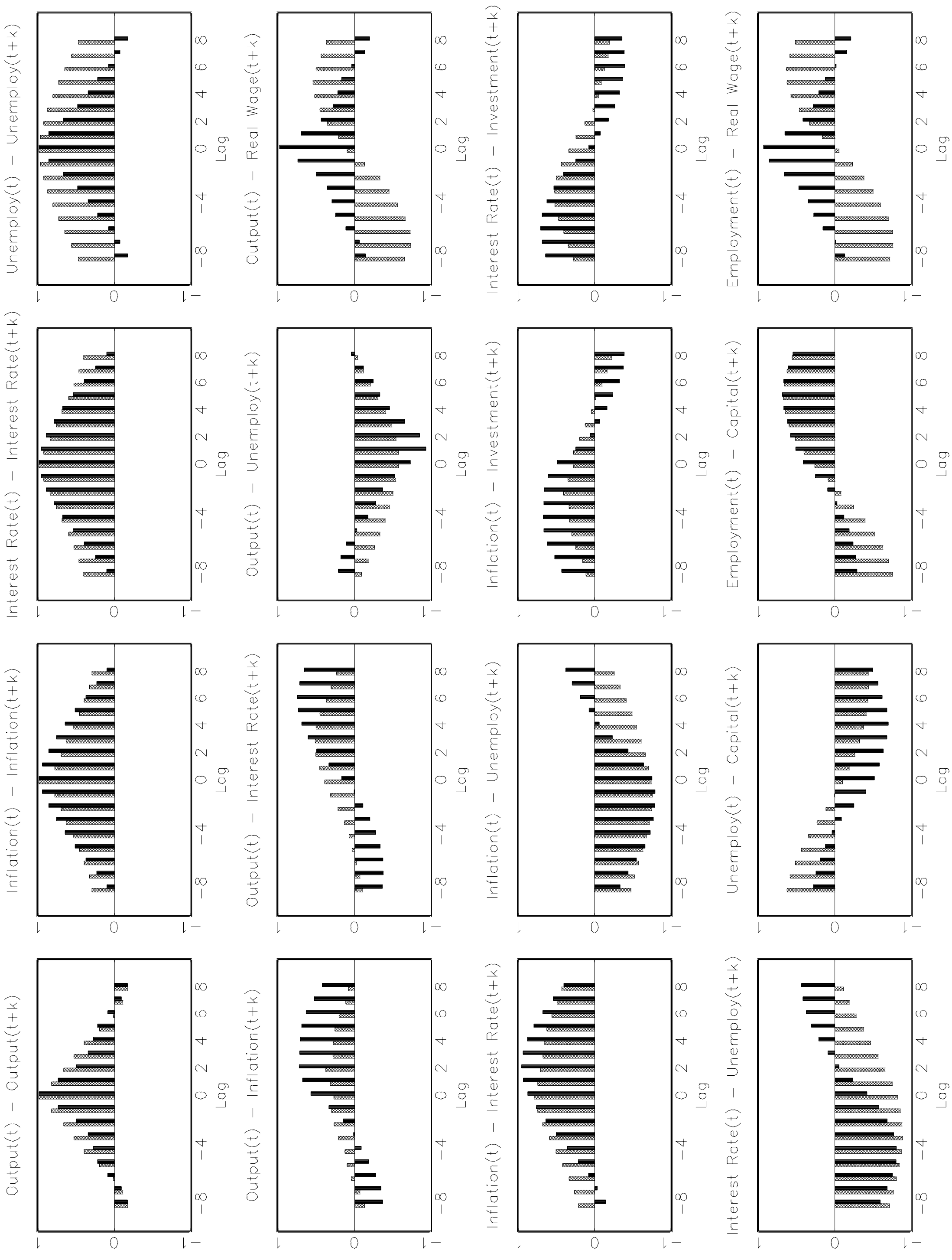

Fig. 1c. Comparison of cross correlations of the DSGE model and the data. (Specification 3).

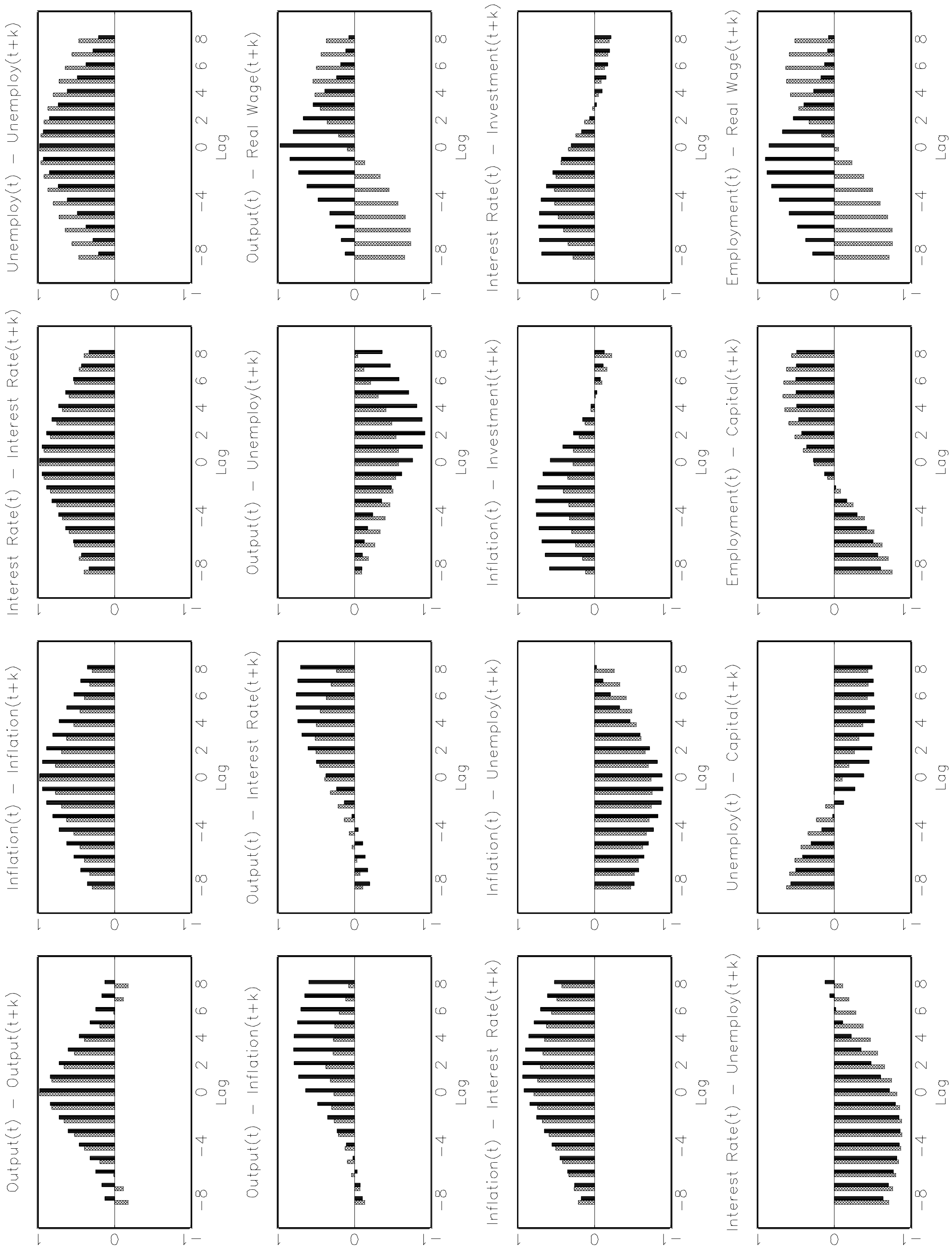

Fig. 1d. Comparison of cross correlations of the DSGE model and the data. (Specification 4).

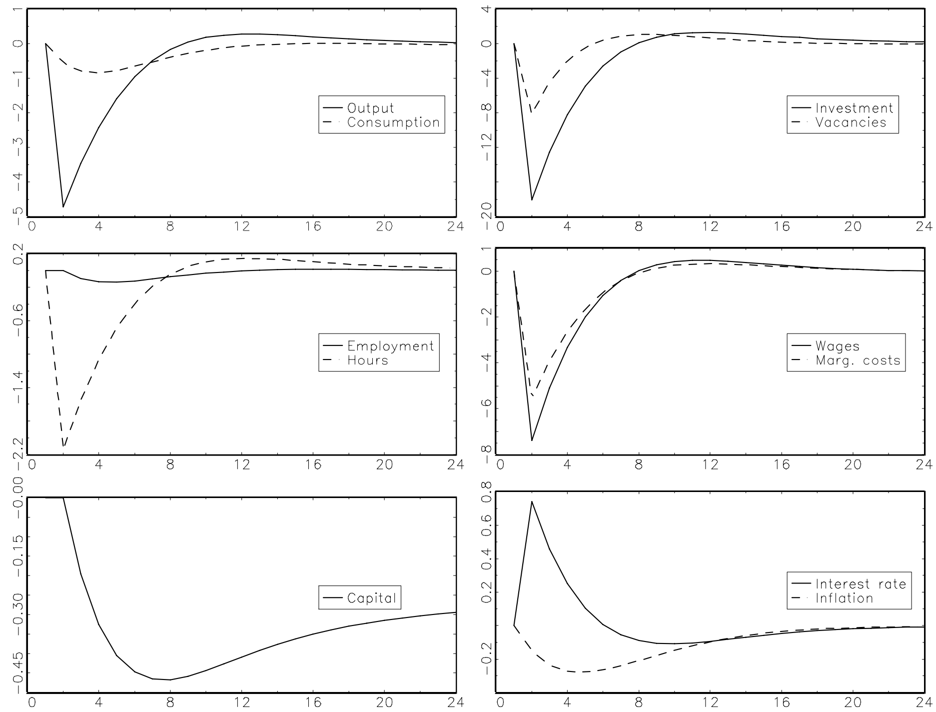

Fig. 2. Responses to a monetary policy shock.

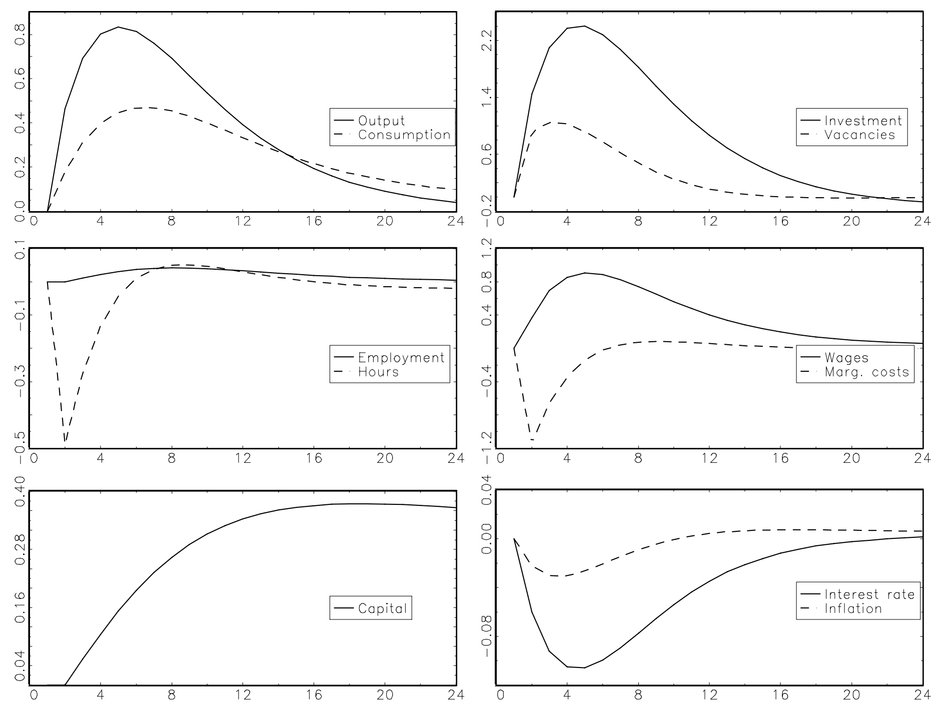

Fig. 3. Responses to a technology shock.

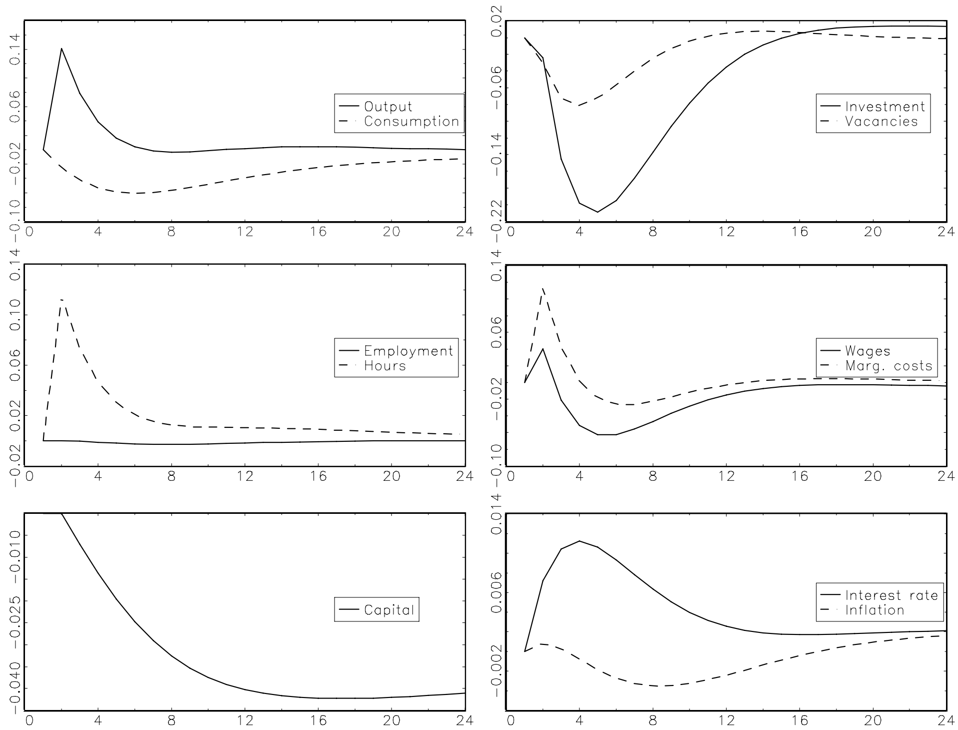

Fig. 4. Responses to a government spending shock.

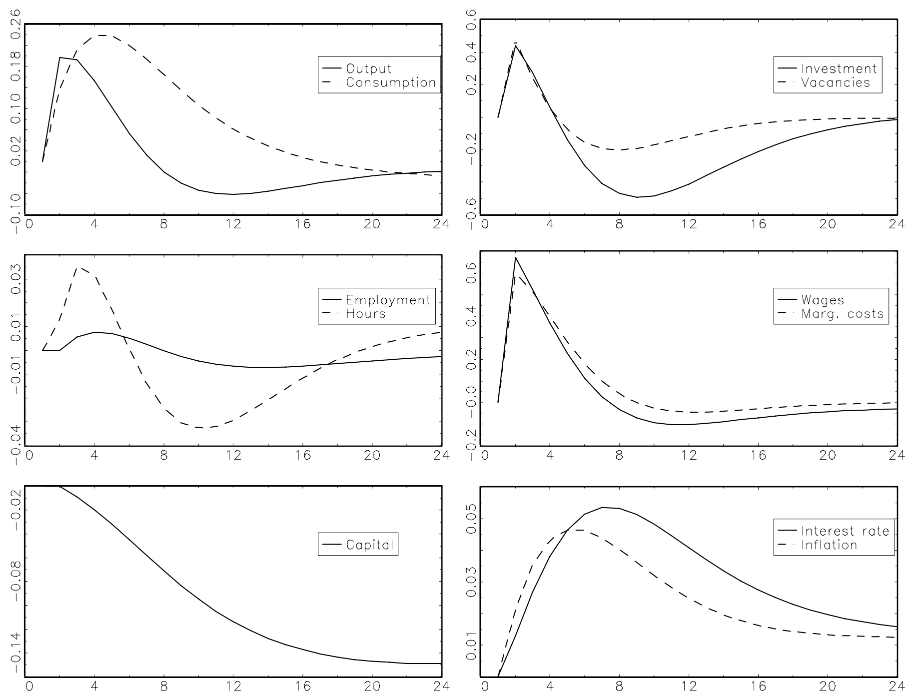

Fig. 5. Responses to a preference shock.

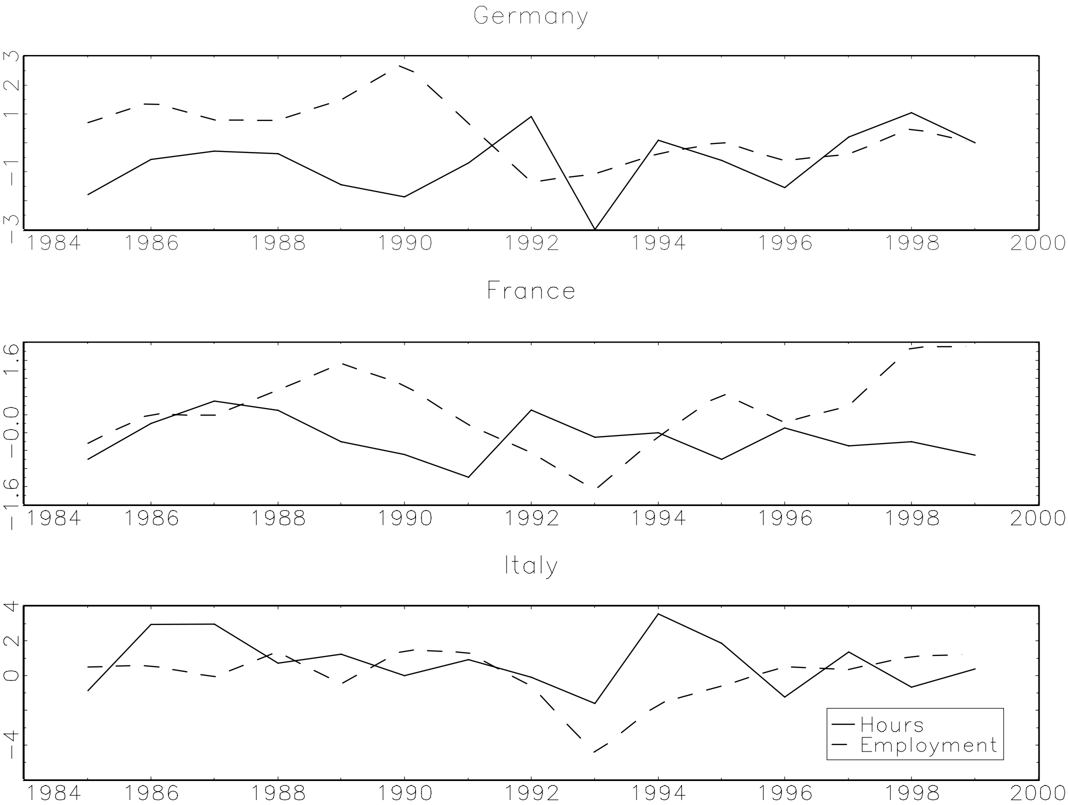

Fig. 6. Annual growth rate of the hours worked and employment.
Source: Bureau of Labour Statistics

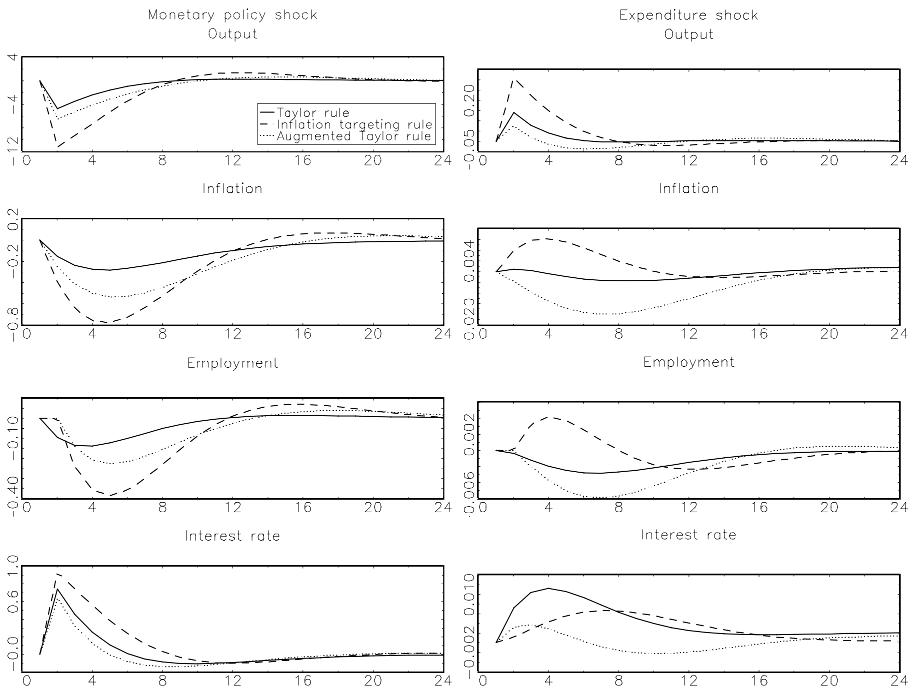

Fig. 7. Dynamic responses of several rules.

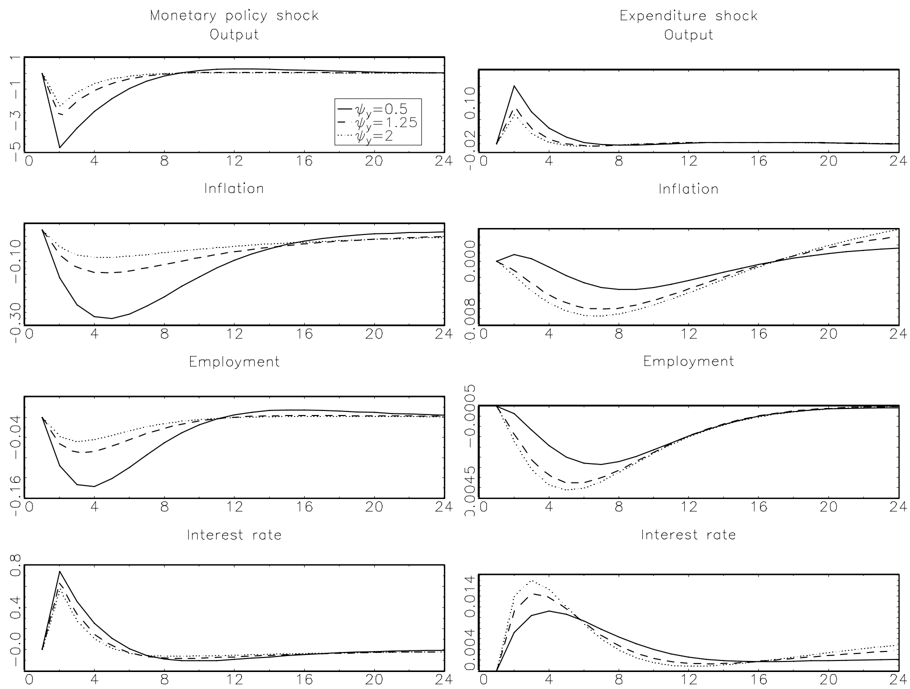

Fig. 8. Dynamic responses according to the weight on output in the rule.

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