Dynamic Response to Monetary Shocks in a Search Model of the Labor Market*

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Abstract

This paper studies the dynamic response of a few key macroeconomic variables to each one of three exogenous shocks: monetary, government spending and technological shocks. By using a cash in advance model with two market frictions, one in the intermediation of loanable funds, and one in the labor market, we address the ability of the model to simulate data embedded with the same dynamic response to shocks observed in historical data (i.e we estimate dynamic multipliers to exogenous shocks by estimating a VARX model to both sets of data). We find evidence on the short run expansionary effects of monetary policy and we highlight the importance of studyng the real interest rate dynamics as opposed to the nominal interest rate. In terms of the former we do observe a coutercyclical movement of money and interest rates, while in term of the latter, we don't. We also find a good performance of the model in tracing out the dynamic response of output after any one of the three shocks. Investment and employment dynamics are well reproduced when the economy is subject to government spending or technological shocks. We make a case for using this particular validation technique as a complementary alternative for testing the performance of calibrated dynamic general equilibrium models (JEL Codes: E3, E52, C32).

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1 Introduction

We trace down the effects on a few key macroeconomic variables of three different types of exogenous shocks to the economy. Namely, monetary policy shocks, government spending shocks and technological shocks.

The statistical approach used to analyze historical data, the estimation of Vector Autoregression models with Exogenous variables (VARX models), provides a natural validation technique for calibrated dynamic general equilibrium models. We apply this idea to analyze the ability, of a simple cash in advance model with one financial and one labor market friction to reproduce the observed dynamics in historical data. That is, using a VARX model we study the dynamic response of output, consumption, investment, employment, hours per worker and interest to each one of three exogenous shocks. We then simulated artificial data using our theoretical model and apply the same statistical tools used for historical data to simulated data.

Our theoretical model has two distinctive features. First, we assume there is a financial friction that we model as a cost that household's face for managing their portfolio of deposits at the financial intermediary. The second friction is in the labor market. By recognizing that finding a job is an economic activity, we give up with the traditional price mechanism for the allocation of labor and model this market as in the labor search literature. As explained in a previous paper (Riascos [2002]) this markets frictions play an important role in reproducing two stylized facts of post war U.S. data. First, the short run expansionary effects on output and employment of monetary policy and second, the strong positive correlation between all measures of labor supply and inflation (i.e. a short run Phillip's Curve).

We find evidence on the short run expansionary effects of monetary policy and we highlight the importance of studying the real interest rate dynamics as opposed to the nominal interest rate. In terms of the former we do observe a coutercyclical movement of money and interest rates, while in term of the latter, we don't. We also find a good performance of the model in tracing out the dynamic response of output after any one of the three shocks. Investment and employment dynamics are well reproduced when the economy is subject to government spending or technological shocks.

Also, we illustrate how we lose information when analyzing artificial data using an appropriate statistical tool rather than relying on the true data generating process. This is exactly what we are forced to do with real data. We make case for using this particular validation technique as a complementary alternative for testing the performance of calibrated dynamic general equilibrium models.

This paper is organized as follows. The second section briefly explains the theoretical model. Section three motivates and explains the statistical model we used for analyzing the data. Section four put's together some results, and the last section concludes.

2 A Cash in Advance Model with Financial and Labor Market Frictions.

In this section we will briefly explain the model used in the paper.[1] The basic skeleton of our model is an RBC model with a cash in advance constraint in consumption. We then introduce two market frictions: A simple financial friction in the intermediation of loanable funds and a labor market friction as in the search literature.

The first friction attempts to rationalize the liquidity effect and the expansionary effects of monetary policy.[2] The basic intuition is very simple. Firms demand cash in order to pay the wage bill and finance investment. All loans are intermediated through the banking system where households deposit their money and get paid the nominal interest rate. The friction we introduce is a cost in terms of resources for households changing their portfolio of deposits.[3] The central bank trades bonds with banks (financial institutions in general). By using open market operations, the central bank can unexpectedly inject cash into the market. Since households are penalized for changing their portfolio of deposits at the financial intermediaries, the excess liquidity will tend to lower the interest rate. A fall in the interest rate lowers the cost of loans for firms therefore, stimulating investment and labor demand.

[1] A complete explanation and motivation for this model can be found in Riascos [2002].

[2] This type of friction is motivated by the limited participation literature. It is closely related to the time cost introduced by Christiano and Gust [1999]. In particular the modeling device used here is the one used by Cooley and Quadrini [1999a].

[3] For example, the redemption of ceretificates of deposits before their maturity date is tipically penalized by paying a lower interest rate than the one agreed at the time it was bought.

The second friction is motivated by the idea that trade in the labor market is an economic activity, uncoordinated, time consuming (i.e. for firms, labor as well as capital require time to become productive and for households, finding a job requires searching), and costly (firms spend resources posting vacancies for being filled). Therefore, we give up with the traditional price mechanism for the allocation of resources and adopt a search view of the labor market. We have found this friction useful for reproducing the strong positive correlation of output with all measures of labor supply observed in U.S economy (a short run Phillips Curve). Furthermore, it runs out that this labor market friction considerably amplifies monetary shocks in our model.

2.1 Labor Search and Portfolio Rigidities.

We look at the labor market as consisting of two sectors: one for trade and one for production, meaning that only unemployed workers look for a job (there is no on the job search). We take the separation process as exogenous.[4]

There is large number of identical households, a large number of large firms (i.e., each firm hires many workers and posts many vacancies), a representative financial intermediary, a representative unemployment insurance firm and a consolidated fiscal and monetary authority (the Central Bank).

The economy is subject to monetary, government spending and technological shocks. Let S_t stand for the state of all exogenous shocks realized at the beginning of period t. Population is normalized to unity.

2.2 The Labor Market.

At the beginning of every period, vacancies posted by firms, and job searching workers are matched with a probability implicitly defined by the following aggregate matching technology:

$$X_t = F^m(V_t, eU_t) = A_t^m V_t^{\theta^m} (eU_t)^{1-\theta^m}$$

where X_t denotes the number of realized matches between workers and firms vacancies (i.e. number of workers moving from unemployed to employed), V_t is the vacancy rate, U_t is the unemployment rate and e is the aggregate search intensity of the unemployed workers of the economy (we take e as exogenously given). This Cobb

[4] This specification draws heavily on Andolfatto [1996] and Pissarides [1990].

Douglas specification is consistent with Blanchard-Diamond (1989) empirical study. Moreover, in a growing economy, it is the only one consistent with balanced growth.[5] For simplicity, we assume the separation rate s to be exogenous and constant. That is, if at the beginning of period t, n_t^j is the employment rate in firm j, then sn_t^j will be the fraction out of total population that losses their job during the period.

The rate at which firms fill in their vacancies is: $q_t(\theta_t) = \frac{X_t}{V_t} = F^m(1, \theta_t^{-1})$ where $\theta_t = \frac{V_t}{eU_t}$ is called the labor market tightness, note that $q_t'(\theta_t) < 0$ (the more tight the labor market is, the harder is to fill in vacancies for firms). Its elasticity with respect to θ is, $1 - \theta^m \in (-1, 0)$

The rate at which households move from unemployment to employment per unit of search intensity is: $\theta_t q_t(\theta_t) = \frac{X_t}{eU_t}$. Hence, from the point of view of firms, employment evolves according to:

$$n_{t+1}^j = (1-s)n_t^j + q_t(\theta_t)V_t^j \qquad \text{(for each firm } j\text{)}$$

where n_t^j is the employment rate during period t.

The dependence of the transition functions on the tightness of the labor market highlights the trading externalities implicit in the labor market search.

At the beginning of every period all shocks are realized. Firms and agents enter in a bargaining process in which the terms of the labor contract are specified. That is, the amount of labor input required, h and the real wage, w. Once the contract is specified, firms and households trade in all other markets.

2.3 Financial Intermediation.

Households do not lend directly to firms. At the beginning of every period t, the state of the economy is completely revealed and households decide how much money D_{t+1}, they will deposit until the end of the period at the financial intermediary. At the same time, the financial institution decides how many bonds B_{t+1} to hold until the end of the period. Bonds are bought to the central bank. Firms borrow cash in order to finance the wage bill and investment. Formally, the supply of loanable funds in period t is: $D_{t+1} - B_{t+1}$ and the demand by firms is $w_t p_t h + p_t I_t$, where w_t is the real wage, p_t is the general price level and h_t is the amount of labor supplied by

[5] See Pissarides [1990].

the representative household. Ultimately, households are also the owners of the financial institutions. Since we assume there is perfect competition and free entry and exit, in equilibrium, financial intermediaries profits are zero.

2.4 Firms.

We assume that each firm j requires many workers and posts many vacancies every period. Immediately after the bargaining process has finished, firms make their investment decisions I_t^j and post vacancies V_t^j. The information set for the firm is: exogenous shocks, individual states k_t^j (firms capital stock) and n_t^j (rate of employment of the firm), and the corresponding aggregate ones.

Firms borrow from the financial intermediary in order to finance investment and to pay the wage bill at the beginning of the period as required by the labor contract. At the end of the period, firms pay dividends. Each household receives his corresponding amount of per capita total dividends. Because of the cash in advance constraint, dividends paid today (at the end of the period) can only be used for consumption until next period. Hence, form the point of view of households, one unit of dividends in period t is worth $\beta\frac{U_1(c_{t+1}^n,h_{t+1})}{U_1(c_t^n,h_t)}\frac{p_t}{p_{t+1}}$ units of consumption good at time t.[6] Since firms are ultimately owned by households, then it is reasonable to assume the following behavior for the firm.

$$\max E\sum_{t=0}^{\infty}\beta^{t+1}\frac{U_1(c_{t+1}^n,h_{t+1})}{U_1(c_0^n,h_0)}\frac{p_t}{p_{t+1}}\pi_t^f$$

$$\begin{aligned} n_{t+1} &= (1-s)n_t + q_t(\theta_t)V_t \\ k_{t+1} &= (1-\delta)k_t + I_t \end{aligned}$$

Where $\pi_t^f = A_t^{tec}k_t^\theta\,(h_t n_t)^{1-\theta} - (1+i_t)(w_t n_t h_t + I_t) - V_t\kappa_t$ and κ_t is the real cost of posting one vacancy[7].

[6] Actually $\frac{N_{t+1}U_1(c_{t+1}^n,h_{t+1})+(1-N_{t+1})U_1(c_{t+1}^u,e)}{N_tU_1(c_t^n,h_t)+(1-N_t)U_1(c_t^u,e)}\frac{p_t}{p_{t+1}}$, but as we'll show later, the existence of a perfect insurance market for unemployment guarantees that in equilibrium $U_1(c_t^n,h_t) = U_1(c_t^u,e)$

[7] We calibrate this cost in steady state to 10% of output. In order to abstract from substantial wealth effects, we asume this is not a social cost. That is, the government collects this at no cost and returns it to agents as a lump sum transfer.
In any case, one can always interpret this cost as an investment cost.

2.5 Households.

Immediately after the bargaining process has finished, households make their consumption $c^n, c^u$and financial decisions (cash holdings M_t and deposits D_t at the financial intermediary). In order to avoid the ex-post heterogeneity due to the employment status of each household, we assume there is a perfectly competitive insurance market (heterogeneity would considerably increase the complexity of solution). Every period households also choose $\overline{B}_t$, the amount of insurance they buy for the next period. Moreover, we also assume that this unemployment insurance must be bought with cash so that it plays a role only to the extent that there is no uncertainty on the workers employment status. If that wasn't the case, this additional security would be demanded by households, just because it allows to buy resources and exchange them for cash within the same period.

When the bargaining process is finished, agents still don't know of their employment status therefore, they evaluate their decisions based on their expected value of being employed or unemployed. Once the contract is signed, they believe to have no power on the probability of being employed or unemployed (its only when they are bargaining that they consider the possibility of affecting their transition rate based upon their individual search effort).

It follows that households problem is:

$$\begin{aligned}
&\max E\left[\sum_{t=0}^{\infty}\beta^t(N_t U\left(c_t^n, h_t\right) + (1-N_t)U\left(c_t^u, e\right))\right] \\
&M_{t+1} + p_t c_t^n + \overline{p}_t\overline{B}_t + p_t\tau_t = (M_t - D_{t+1}) + (1+i_t)D_{t+1} + p_t w_t h_t - \\
&\qquad\qquad p_t\phi(D_t, D_{t+1}) + p_t d_t^f + p_t d_t^{int} \\
&M_{t+1} + p_t c_t^u + \overline{p}_t\overline{B}_t + p_t\tau_t = (M_t - D_{t+1}) + (1+i_t)D_{t+1} + \overline{B}_t - \\
&\qquad\qquad p_t\phi(D_t, D_{t+1}) + p_t d_t^f + p_t d_t^{int}
\end{aligned}$$

$$\begin{aligned}
&p_t(c_t^n + \phi(D_t, D_{t+1})) + \overline{p}_t\overline{B}_t \leq M_t - D_{t+1} + p_t w_t h_t \\
&p_t(c_t^u + \phi(D_t, D_{t+1})) + \overline{p}_t\overline{B}_t \leq M_t - D_{t+1} + \overline{B}_t
\end{aligned}$$

Where $\overline{p}_t$ is the price of an insurance contract that promises to pay $\overline{B}_t$ in the event of being unemployed. The expected profits of the representative insurance company are: $\overline{p}_t\overline{B}_t - (1-N_t)\overline{B}_t$. Perfect competition in the insurance market implies that in equilibrium, $\overline{p}_t = 1 - N_t$.

For future reference, we will assume household's instantaneous utility to be separable: $U\left(c_t^n, h_t\right) = \log(c_t^n) + \Gamma(h)$ and $U\left(c_t^u, e\right) = \log(c_t^u) + \Gamma(e)$.

2.6 Consolidated Monetary and Fiscal Authority.

Every period t the monetary authority prints money $M_{t+1} - M_t$ where M_t is the stock of money, collects taxes, pays interest on bonds B_{t+1} to the financial intermediary, finance exogenous government expenditures g_t and collects at no cost the cost of intermediation $\phi(D_t, D_{t+1})$ (i.e. the cost of changing households portfolio). This assumption is not crucial for results to go through but it emphasizes the intertemporal distortions of this financial friction rather than the wealth effect of such a cost. Therefore the consolidated fiscal and monetary authority budget constraint is:

$$M_{t+1} - M_t + p_t \tau_t + p_t \phi(D_t, D_{t+1}) = i_t B_{t+1} + p_t g_t$$

We assume government expenditures follow an exogenous autoregressive process:

$$Log(g_{t+1}) = \rho^g Log(g_t) + (1 - \rho^g) Log(g) + \varepsilon_{t+1}, \varepsilon_{t+1} \sim N(0, \sigma^g)$$

Where g is the mean of the process, ρ^g is the autocorrelation coefficient and σ^g is the standard deviation of the innovation process.

2.7 Monetary Policy.

We will study the implied dynamic response of our model under monetary policy shocks.

Using open market operations, the monetary authority exogenously sets the rate of growth of money supply. That is, at the beginning of every period t, the monetary authority exogenously sets the rate of growth of money used for transactions: $M_t - B_t$. We take M as constant and specify monetary policy as:

$$M_{t+1} - B_{t+1} = (M_t - B_t) \mu_t$$

where $\log(\mu_t)$, the rate of growth of money supply, follows the following autoregressive process:

$$\log(\mu_{t+1}) = \rho^\mu \log(\mu_t) + \varepsilon_{t+1},\ \varepsilon_{t+1} \sim N(0, \sigma^\mu)$$

2.8 The Bargaining Process:Wages and labor supply.

Details on the bargaining process can be found in Riascos [2002]. Here we just recall the two basic equations that close our model:

$$w_t h_t = \frac{\xi\left(\frac{\beta U_1(c^n_{t+1}, h_{t+1})}{U_1(c^n_t, h^n_t)} \frac{p_t}{p_{t+1}} \frac{\partial F^{tec}(k_t, n_t h_t)}{\partial n_t} + e\theta\kappa\right) + (1-\xi)\frac{(\Gamma(e) - \Gamma(h_t))}{U_1(c^n_t, h^n_t)}}{\xi(1+i_t)\frac{\beta U_1(c^n_{t+1}, h_{t+1})}{U_1(c^n_t, h^n_t)} \frac{p_t}{p_{t+1}} + (1-\xi)}$$

and

$$\Gamma'(h_t) = -\frac{U_1(c_t^n, h_t)}{1+i_t}\frac{\partial^2 F^{tec}(k_t, h_t n_t)}{\partial h_t \partial n_t}$$

The above two equations determine h and w.

Finally we can compute the flow of dividends that each agent receives every period. Since we have normalized population to unity and households own firms, individual dividends are equal to aggregate profits $(d_t^f = \pi_t^f)$. On the other hand, perfect competition in the financial sector implies that profits from financial intermediation are zero $\left(d_t^{int} = 0\right)$.

2.9 Functional Forms and Calibration.

Appendix II provides a description of the data. We used the following standard functional forms in our model. As we said before, the matching technology is assumed to take the Cobb-Douglass form:

$$F^m(V_t, eU_t) = A_t^m V_t^{\theta^m} (eU_t)^{1-\theta^m}.$$

Each firm's production technology is a Cobb-Douglass production function:

$$F(k_t, h_t n_t) = A_t^{tec} k_t^{\theta} (h_t n_t)^{1-\theta}.$$

The utility function is separable and contingent to agents employment status as in Andolfatto [1996]. When employed $U(c,h) = Log(c) + \frac{B_e(1-h)^{1-\gamma}}{1-\gamma}$, where B_e is a constant that we calibrate so that in steady state $h = \frac{1}{3}$ and $\frac{1}{\gamma}$ is the intertemporal elasticity of leisure. When agents are unemployed, $U(c,e) = Log(c) + \frac{B_u(1-e)^{1-\gamma}}{1-\gamma}$ where e is agents search intensity that we assume constant and B_u is constant that we calibrate in order to be consistent with a predetermined value of search intensity. Intuitively B_u should be less than B_e as agents value more leisure when they are employed. This turns out to be the case when e is set to $\frac{h}{2}$. In general terms, our calibration is the same as the one presented in Andolfatto [1996] with regard to our search environment. Of particular interest is the parameter ξ, the workers share of the surplus of a match. Smaller values of ξ amplify the response of employment to shocks[8]. We took $\xi = 0.2$ as an reasonable intermediate value.

[8] This is comparable to what Cooley and Quadrini [1999a] report.

Our calibration is completely standard except for the scale parameter ϕ. We choose ϕ such that the implied liquidity effect resembles the one documented in the empirical literature.[9] As suggested previously, we fit AR(1) processes to technological and government spending shocks.

The relevant parameter values are summarized in Tables 1 and 1.1(See Appendix II for a description of the data set we used).

β	γ	θ	ϕ	δ	ρ^A	ρ^g	σ^A	σ^g
0.99	2	0.36	0,10	0.025	0.99	0.98	0.007	0.009
Table 1								

g/y	h	e	q	θ^m	ξ	$\frac{\kappa V}{Y}$
0.1	1/3	1/6	0.9	0.6	0.2	0.1
Table 1.1						

From a dynamic optimization perspective, our model comprises of three exogenous and uncorrelated state variables (i.e. monetary, government spending and technological shocks) and five endogenous state variables (i.e. the stock of capital, the number of employes, the stock of money, deposits and bonds). To solve our model we used the method of log-linearization as explained in King, Plosser and Rebelo [1988].

3 Dynamic Response to Monetary Shocks under the True Data Generating Process.

In this section we illustrate the dynamic response to monetary as implied by the true data generating process that implies that follows from the full theoretical model (except for the information lost when we linearized the dynamic system). We focus in the case of monetary shocks for three main reasons. First, in the following sections, we'll apply certain statistical tools to extract information, on the dynamic response of the economy to exogenous shocks, embedded in the artificially generated series. By comparing this with the one

[9] Christiano, Eichenbaum and Evans [1997] consider the case in which the Fed uses the short interest rate as its policy intrument. A contractionary monetary shock in their model, increases the Federal Funds Rate by 70 basis points. After two quarters there is a sustained decrease in real output of the order of 0.1 to 0.4 %. After 2 years, the contractionary effect fades away.

implied by the true data generating process we make it clear how much information is lost by not knowing the true model behind the series. This calls our attention to be careful when drawing conclusions based only on the impulse response functions and confidence intervals constructed using the true data generating process. The point is, none of this might be present when ignoring the true model and relying on our best tools to extract information from the data. Second, we are particularly interested in the effects of monetary policy and the role of frictions in our model and three, to point out the liquidity effect in terms of real interest rates rather than nominal interest rates.

We fitted an AR(1) process to the rate of growth of money supply. We used $\rho = 0.67$ and $\sigma = 0.008$. Figure 1 reports the impulse response functions after an unanticipated and persistent monetary injection to the economy. We used $\phi = 0$, and $\phi = 10$. The dotted line represents the response of the economy with financial frictions. The working mechanism is the following, after a monetary injection, the inability for households to freely reduce their deposits at the financial intermediary drives interest rates down. By reducing the cost of capital, firms demand more loans to finance investment and pay the wage bill. The financial friction is set so that output expansion is quantitatively similar to the reported in the literature. Notice also the positive response of hours and employment.

4 Model Validation and the Dynamic Response to Exogenous Shocks.

Traditional model validation techniques for these type of calibrated dynamic general equilibrium models include: moment comparisons as in the RBC literature, frequency decomposition of historical and simulated data, implied impulse response functions of historical and simulated data,[10] etc. Here we adopt an alternative approach which consists in comparing the implied dynamic response, of a few key endogenous variables, to each one of three exogenous shocks.[11] We use exactly the same statistical tools to analyze both historical and simulated data, and Vector Autoregressive models with Exogenous variables[12] (VARX) as our main statistical tool.

Our main motivation for this approach stems from our interest in analyzing the economy when it is subject to exogenous shocks.

[10] As in Castaneda [2001].
[11] This is the method proposed in Bruno-Portier [1995].
[12] See Lutkepohl [1991] for the basic theory.

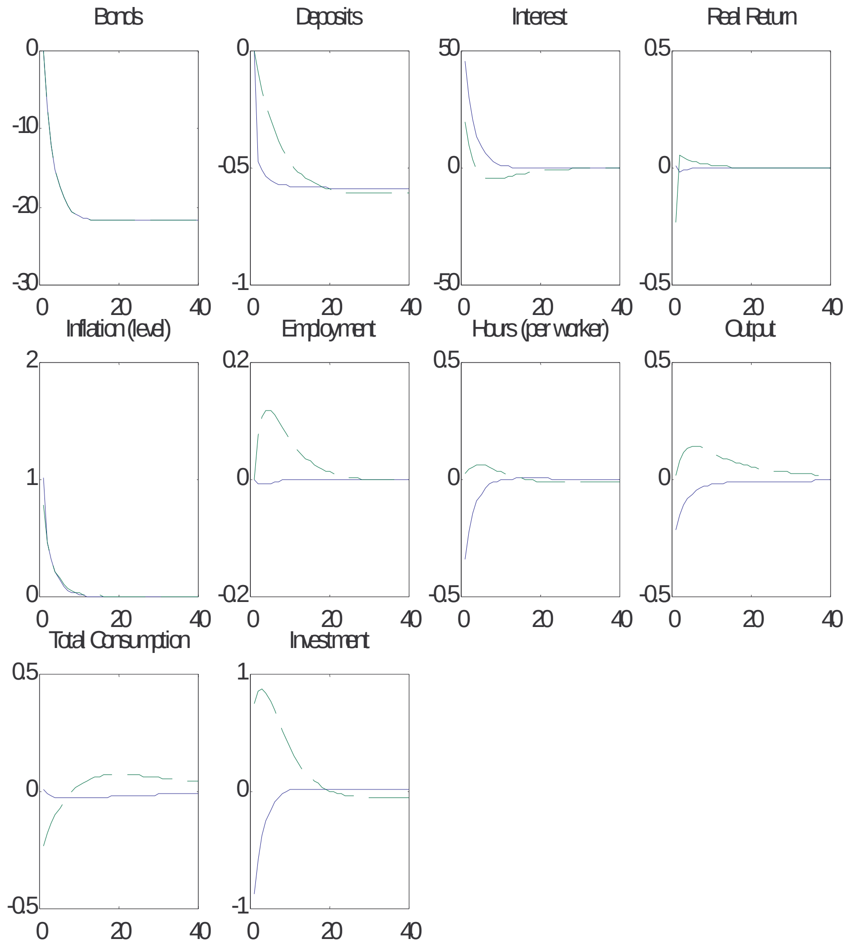

Figure 1: Impulse response functions after a one standard deviation increase in the rate of growth of money supply. All variables except for inflation (which is in levels) are in percentage deviations from steady state. The dotted line corresponds to the economy with portfolio adjustment costs. The other line corresponds to the frictionless economy.

Most of the time, this is not only the main subject of interest, as for example, when we want to trace the effects of exogenous policy shocks across the economy, or when we want to know the importance of one particular kind of shock versus another. But, it is also one of the major building blocks in writing theoretical models. That is, when modeling, one is usually thinking about the particular impact that one specific shock or policy has on the rest of the variables of the model. For example, in our model, we introduced a financial friction in order to reproduce the short run expansionary effects of monetary policy. Therefore, we want to address in a rigorous way if this particular dynamics is revealed when we apply the appropriate statistical tools to both historical and simulated data. In short, it is the subject of interest (to trace the dynamic effect across the economy of the different shocks), and our modeling guidelines, what motivates this particular validation proposal: to compare the implied dynamic response of our model economy to exogenous shocks with the dynamic response implied by the historical data. This considerably narrows the set of statistics we want to match in our model.

Another issue is the particular statistical model we use to study this type of dynamics. For example, one good candidate could be to estimate the implied impulse response function of our model with the ones implied by the data. At least two things restrain us from pursuing this particular approach. First, when estimating the impulse response functions of a VAR model, one has to take a stance on the degree of exogeneity of one variable versus another one (typically, a Cholesky decomposition). This is an interesting avenue but it doesn't exploit some other natural restrictions built-in our theoretical model (i.e. the fact that there are three exogenous shocks driving our model economy). And second, by estimating a VARX model on some endogenous variables of interest, and using the exogenous shocks as our exogenous variables, we by-pass any problem related to the degree of exogeneity of the endogenous variables and we keep faithful to the theoretical model (i.e. that there are only three exogenous variables and all other variables are simultaneously determined within the model). We want also to use this to narrow further our statistical model. Thus, a VARX model seems appropriate to address the questions we want.

4.1 The Statistical Model.

We estimate two different statistical models based on two sets of relevant macroeconomic variables. Two criteria where used in this selection. First,we wanted to include all relevant macroeconomic variables for which our model had something to say (that would include output, consumption, investment, employment, hours per worker, the real wage, the interest rate, the price level, etc.) and second, we chose those variables for which we could apply exactly the same statistical tools to both historical and simulated data without need of any additional restriction on the set of estimated parameters. Appendix I reports the results for a few other interesting models for which estimation was straight forward using historical data but for which we found some estimation problems using simulated data.[13]

All models we estimated where of the form:[14]

$$z_t = A_1 z_{t-1} + ... + A_p z_{t-p} + B_0 x_t + \mu_t$$

where z_t is a column vector of endogenous variables, x_t is a column vector of exogenous variables, A_i, B_j are real matrices and μ_t is an error vector.

We will estimate models by extracting from the following endogenous variables: real output per capita (y), real private consumption per capita (y), real investment per capita (inv), the employment rate (n), hours per worker (h) and the interest rate (i). All variables are in log's except for the interest rate. The exogenous variables used in all models where: stock of money per capita (m), real government spending per capita (g) and total factor productivity (a). All exogenous variables are in logs.

We used both historical and simulated data for every model and applied exactly the same transformations and statistical tools to both sets of data. For historical data we used Schwartz Criterion to select p and used the same p for estimations using the simulated data. The data sets we used is explained in Appendix II.

In all figures, 90 % confidence intervals, represented by dotted lines, where constructed using historical data.[15] Continuous lines

[13] In particular, a collinearity problem. For example, in our model, all spending, except government spending, is carried using cash. This implies that, to a first order aproximation, if output, prices and the stock of money are all included in the same VARX the matrix of explanatory variables woundn't be of full rank.

[14] All codes where written by the author in MatLab. The excellent Econometrics Toolbox by James P. La Sage, available at http://www.spatial-econometrics.com/, was particularly usefull.

[15] Conditional on the vector of exogenous variables, Monte Carlo experiments were performed in the following way. We simulated 500 artificial vector series z_t, each one of length 134, using the VARX model estimated from historical data series and using a Gaussian

represent the dynamic response to shocks implied by the model estimated from the simulated data. We used the standard deviation of shocks implied by historical data.[16]

4.1.1 Model I

Let z_t be a five dimensional column vector $(y_t, inv_t, n_t, h_t, i_t)'$ of endogenous variables and x_t the three dimensional column vector of exogenous variables $(m_t, g_t, a_t)'$.

Based on Schwartz criteria, we set $p = 1$. Panels 1.1 through 1.3 at the end of the paper, show the response of each one of the endogenous variables to each one of the exogenous shocks. Each shock is of one standard deviation. All variables are shown in percentage deviation from steady state, except the interest rate which is shown as an absolute deviation from steady state (measured in basis points).

Panels 1.1.1 through 1.3.1, is the same as the previous model but when we use $p = 2$. All variables are shown as percentage deviation from steady state, except the interest rate which is shown as an absolute deviation from steady state (measured in basis points).

4.1.2 Model II

Let z_t be the six dimensional column vector $(y_t, c_t, inv_t, n_t, h_t, i_t)'$ of endogenous variables and x_t the three dimensional column vector of exogenous variables $(m_t, g_t, a_t)'$.

Based on Schwartz criteria, we set $p = 1$. Panels 2.1 through 2.3 at the end of the paper, show the response of each one of the endogenous variables to each one of the exogenous shocks. Each shock is of one standard deviation. All variables are shown in percentage deviation from steady state, except the interest rate which is shown as an absolute deviation from steady state (measured in basis points).

Panels 2.1.1 through 2.3.1, is the same as the previous model but estimated in differences. All variables are shown as absolute deviations from steady state growth rates (measured in basis points)

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white noise process. For each artificial time series we esimated the 20 period dynamic response to each shock. At every period we choose the 25 highest response and the 25th lowest response.

[16]In general, the simulated shocks had a lower standard deviation than the corresponding one based on historical data. More precisely, the standard deviation of monetary shocks was four time smaller in in simulated data than in historical data. Technological and government shocks standard deviations where not to different in both sets of data.

except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.

4.2 Regularities and Model Performance.

We now address two questions. What does historical data reveal about the dynamic response of variables to each shock and in each statistical model? How good performs the model in simulating artificial data embedded with the same dynamics observed in historical data when analyzed using this particular statistical model?

4.2.1 Model I

Panel 1.1 through 1.3 and 1.1.1 through 1.3.1, support the view that:

a) Monetary expansions have expansionary effects on output.

b) Government spending crowds out private investment and slightly stimulates employment.

c) Technological shocks stimulates output and investment and if anything, stimulates leisure.

In terms of all three shocks, the theoretical model does a good job in generating similar dynamics for output and interest rates. Employment and investment dynamics are well reproduced only under government and technological shocks. None of the shocks gives any information on the dynamics of interest rates.

4.2.2 Model II.

Panel 2.1 through 2.3 and 2.1.1 through 2.3.1, support the view that:

a) Monetary expansions have expansionary effects on output, consumption and investment.

b) Government spending crowds out investment.

c) Technological shocks stimulates output and investment.

In terms of all three shocks, the theoretical model does a good job in generating similar dynamics for output and consumption. None of the shocks give any information on the dynamics of interest rates.

It is interesting to note that across all statistical models estimated, the dynamic response analysis doesn't give us any information on the after shock dynamics of interest rates (independent of the type of shock). Moreover, even though our theoretical model highlights the credit channel in the monetary transmission mechanism, simulated data and historical data are not embedded with any information on the after shock dynamics of interest rates (at least for the set of variables chosen and when analyzed with a simple VARX model[17]). Still, as we pointed out in the previous two sections, we find evidence on the short run expansionary effects of monetary policy.

Therefore, our analysis is silent on the particular monetary transmission mechanism that makes possible the observed short run expansionary effects of monetary policy.

5 Conclusions.

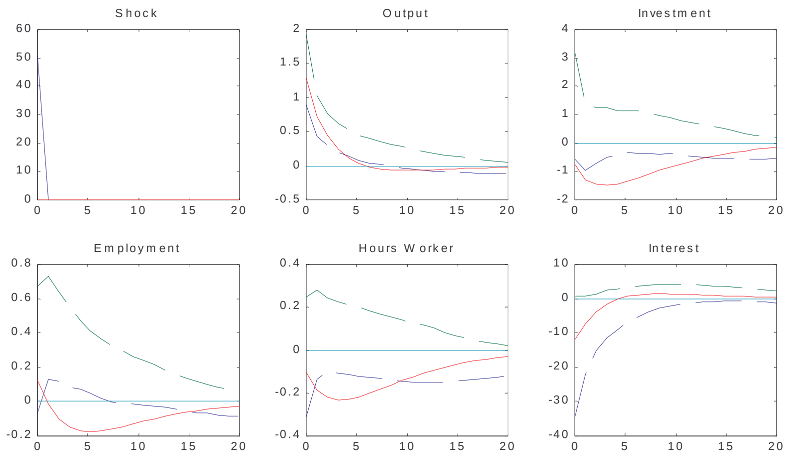
In this paper we have studied the dynamic response of a few key macroeconomic variables to three exogenous shocks: monetary policy shocks, government spending shocks and technological shocks. Using a cash in advance model with two market frictions, a friction in the intermediation of loanable funds and one in the labor market, we have addressed the ability of the model to simulate data embedding the same dynamic response to exogenous shocks as the one we found in historical data.

In order to capture this dynamic behavior, we have estimated a Vector Autoregression model with Exogenous variables (VARX) to both sets of data, historical and simulated. We've found evidence on the short run expansionary effects of monetary policy and no evidence on the way shocks affect interest rates. That is, we find no evidence on the particular monetary transmission mechanism. On the other hand, our theoretical models does a very good job in matching the observed dynamics for at least a couple of important variables. Under all shocks, output and interest rate dynamics are well reproduced (regarding interest rates dynamics, what we basically find is no contradiction between the model and what is implied by historical data, nevertheless the dynamics observed is uninformative). Under government spending and technological shocks, both employment and investment dynamics are well reproduced.

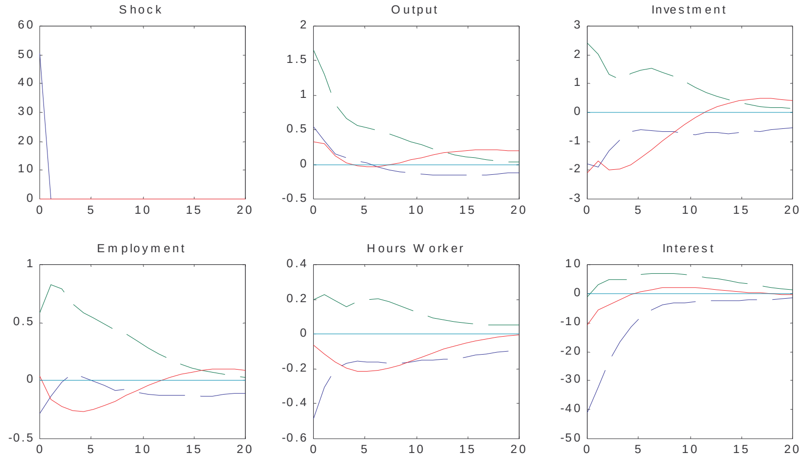
By comparing the above dynamic response of some variables to exogenous shocks, we have provided an additional validation technique to asses the performance of a theoretical model. We argue

[17] Clearly, what this tells us is that in the theoretical model there is much more built-in restrictions than what a few variables can reveal through a simple VARX model.

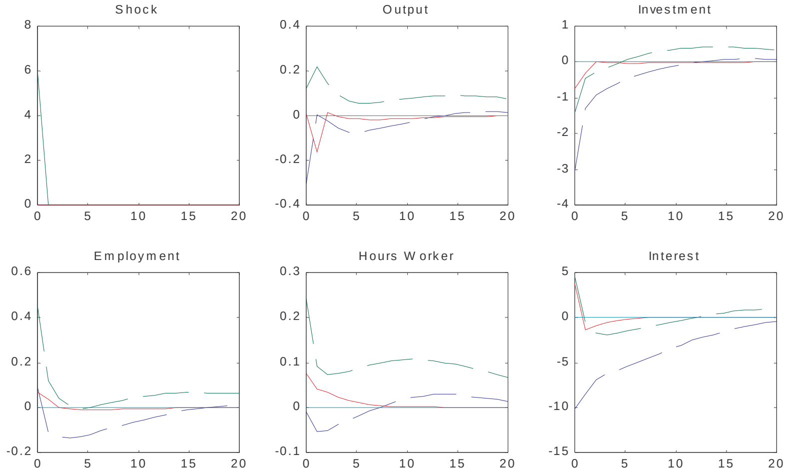
that this validation methodology is a relevant one to study the performance of calibrated dynamic general equilibrium models.



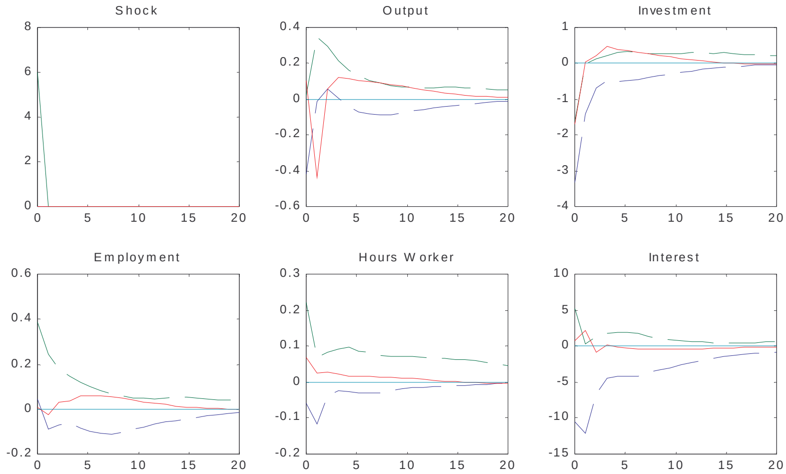
Panel 1.1: Response of each variable to a one standard deviation shock to the stock of money (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



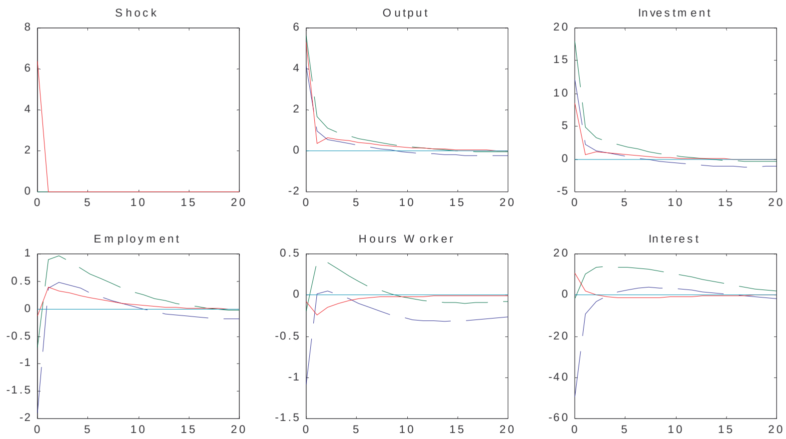
Panel 1.1.1: Response of each variable to a one standard deviation shock to the stock of money (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



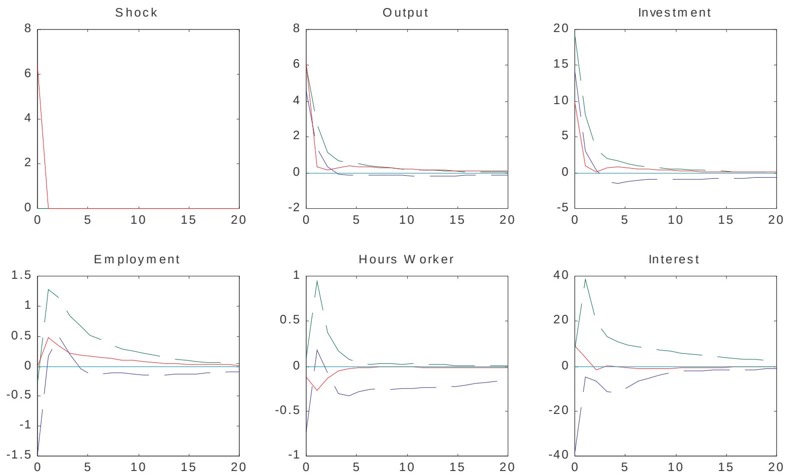
Panel 1.2: Response of each variable to a one standard deviation shock to government spending (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



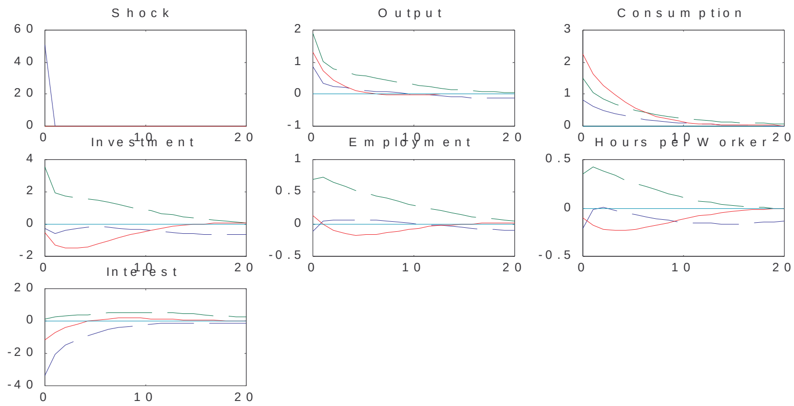
Panel 1.2.1: Response of each variable to a one standard deviation shock to government spending (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



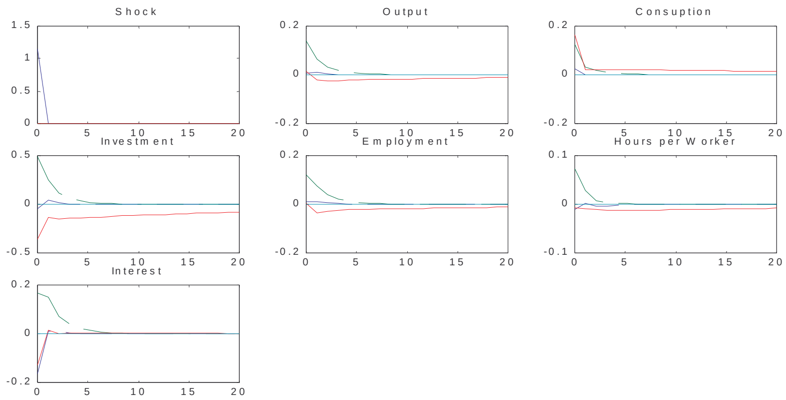
Panel 1.3: Response of each variable to a one standard deviation shock to TFP (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



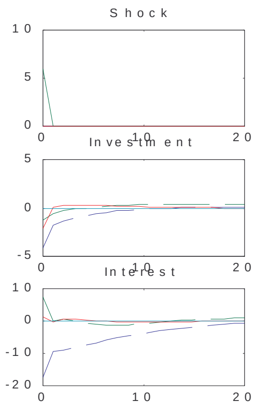
Panel 1.3.1: Response of each variable to a one standard deviation shock to TFP (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



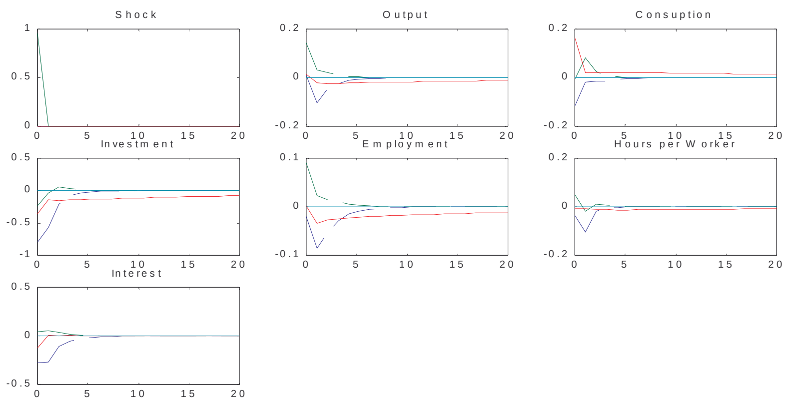
Panel 2.1: Response of each variable to a one standard deviation shock to the stock of money (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



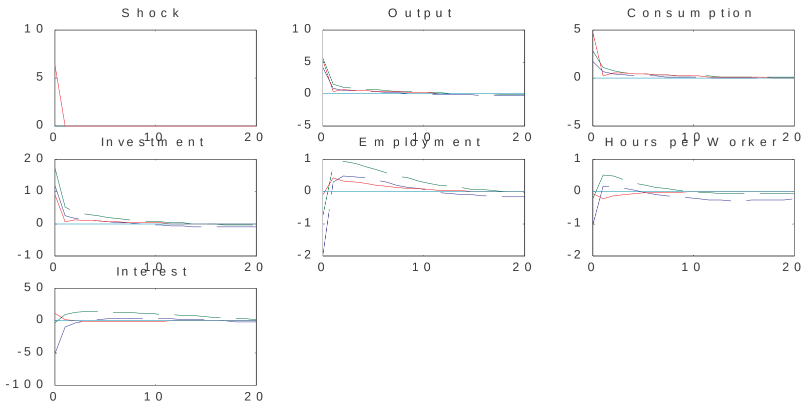
Panel 2.1.1: Response of each variable to a one standard deviation shock to the rate of growth of money. Absolute deviations from steady state growth rates measured in basis points, except interest rates which is in levels.



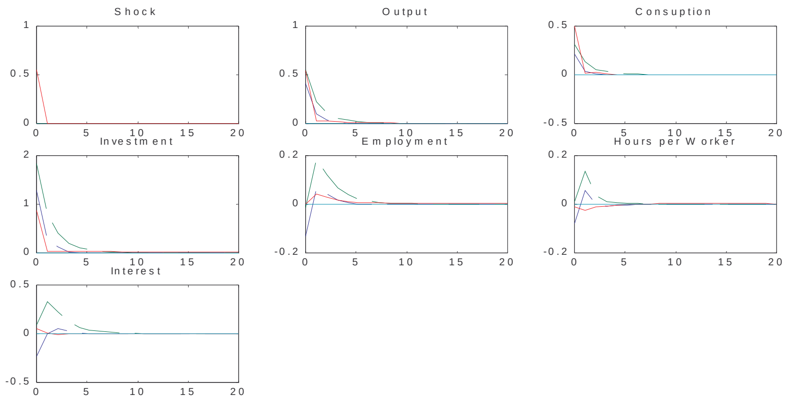
Panel 2.2: Response of each variable to a one standard deviation shock to government spending (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



Panel 2.2.1: Response of each variable to a one standard deviation shock to the rate of growth of government spending. Absolute deviations from steady state growth rates measured in basis points, except interest rates which is in levels.



Panel 2.3: Response of each variable to a one standard deviation shock to TFP (all variables % deviation from steady state except interest rates which is in absolute deviations measured in basis points).



Panel 2.3.1: Response of each variable to a one standard deviation shock to the rate of growth of TFP. Absolute deviations from steady state growth rates measured in basis points, except interest rates which is in levels.

Appendix I.

In this appendix we report results for one more statistical model we have estimated using historical data, and for one more variant of Model I.[18] In this way we provide some sensibility analysis to some of the conclusions we put forward in our conclusions.

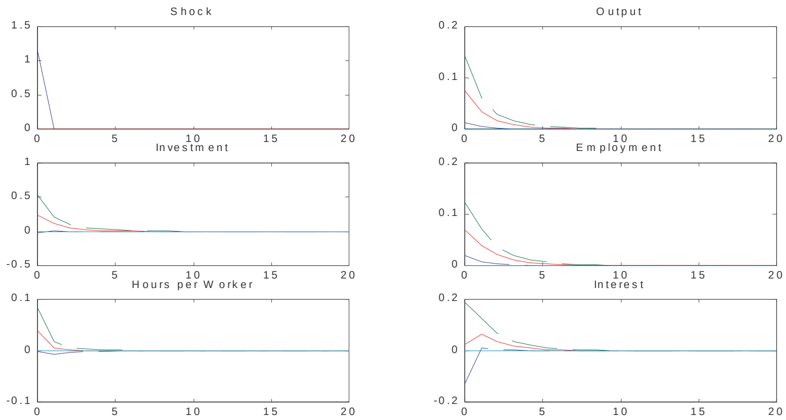
Panels 3.1 through 3.3 show the results of estimating the Model I in differences and when p=1. All variables are shown as percentage deviation from steady state except interest rates (interest rates are expressed as deviations, measured in basis points, from the steady state interest rates).

Panels 4.1 through 4.3 show the results for the following statistical model: let z_t be the be the seven dimensional column vector $(y_t, c_t, inv_t, n_t, h_t, i_t, p_t)'$ of endogenous variables, where p_t is our measure of prices (the log of the GDP deflator) and let x_t the three dimensional column vector of exogenous variables $(m_t, g_t, a_t)'$. The model is estimated in differences, with p=1 and all variables are shown as percentage deviation from steady state except interest rates (interest rates are expressed as deviations, measured in basis points, from the steady state interest rates).

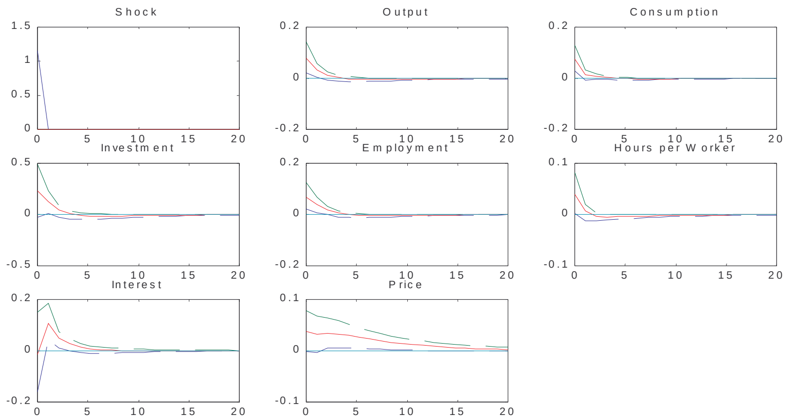
We would like to highlight the following facts. Panels 3.1 and 4.1 provide evidence on the short run expansionary effects of monetary policy (in this case, this is not only reflected by the positive response of output to monetary shocks, but also of employment). Panels 3.2 and 4.2 support the view that government spending crowds out investment. And finally, we find that technological shocks stimulates output, consumption and investment.

With only one exception, that monetary policy can have expansionary effects on employment, each one of the above facts confirm our previous results (those in the main text).

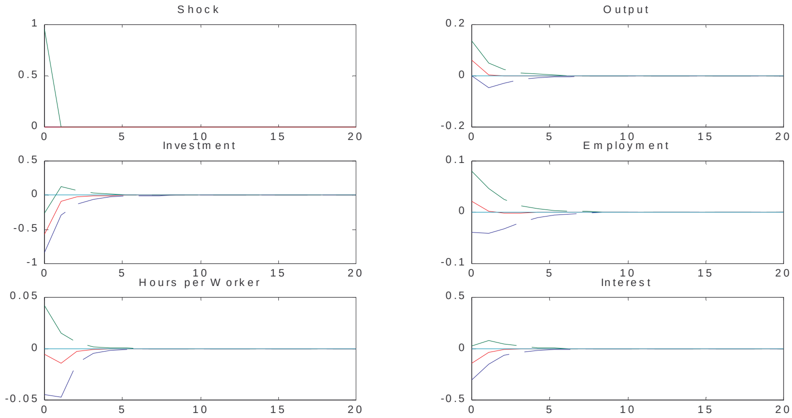
[18] We have estimated a few more statistical models using historical data. We only report results for those cases in which we found statistically significant dynamic reponses to shocks.



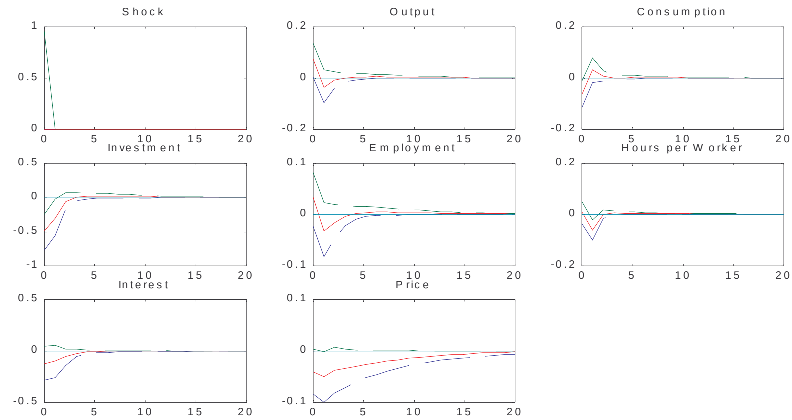
Panel 3.1: Response of each variable to a one standard deviation shock to the rate of growth of money. All variables are shown as absolute deviations from steady state growth rates (measured in basis points) except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.



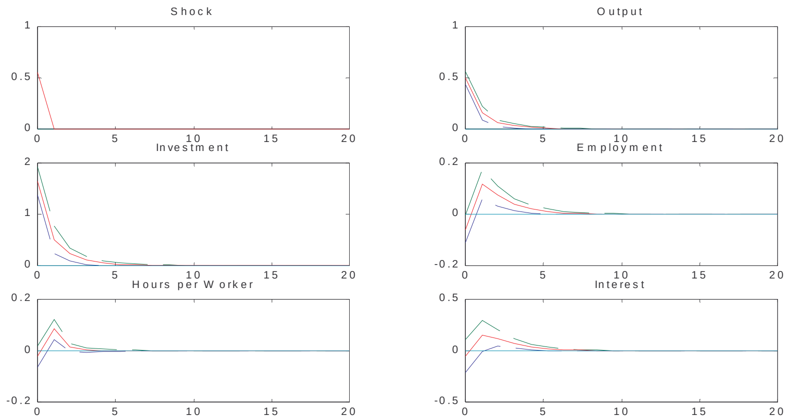
Panel 4.1: Response of each variable to a one standard deviation shock to the rate of growth of money. All variables are shown as absolute deviations from steady state growth rates (measured in basis points) except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.



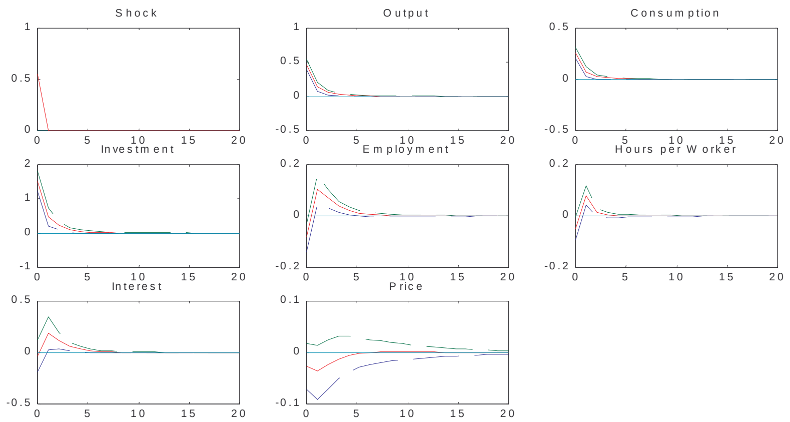
Panel 3.2: Response of each variable to a one standard deviation shock to the rate of growth of government spending. All variables are shown as absolute deviations from steady state growth rates (measured in basis points) except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.



Panel 4.2: Response of each variable to a one standard deviation shock to the rate of grwoth in government spending. All variables are shown as absolute deviations from steady state growth rates (measured in basis points) except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.



Panel 3.3: Response of each variable to a one standard deviation shock to the rate of growth of technology. All variables are shown as absolute deviations from steady state growth rates (measured in basis points) except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.



Panel 4.3: Response of each variable to a one standard deviation shock to the rate of growth of technology. All variables are shown as absolute deviations from steady state growth rates (measured in basis points) except interest rates. Interest rates are expressed as absolute deviations from the steady state interest rates measured in basis points.

Appendix II

A Historical Data

All historical data is taken from DRI Basic Economics 1998. The different tags correspond to the ones used in the data set.

GCNQF: Personal consumption expenditures on nondurables. Billions of constant (1992) dollars, seasonally adjusted at annual rates.

GCSQF: Personal consumption expenditures on services. Billions of constant (1992) dollars, seasonally adjusted at annual rates.

GCDQF: Personal consumption expenditures on durables. Billions of constant (1992) dollars, seasonally adjusted at annual rates.

GGEQF: Government consumption expenditures and gross investment. Billions of constant (1992) dollars, seasonally adjusted at annual rates.

GIFQF: Private fixed investment. Billions of constant (1992) dollars, seasonally adjusted at annual rates.

LHEM: Total employed (household data) thousands of persons, seasonally adjusted, converted from monthly data (average over each period).

LW: Total private hours per week (household data) seasonally adjusted, converted from monthly data (average over each period).

LHUR: Total unemployment rate (household data), seasonally adjusted, converted from monthly data (average over each period).

LHPAR: Labor force participation rate, total16+, converted from monthly data (average over each period).

P16: Total civilian non-institutional population.

GDPD: Gross domestic product: Implicit price deflator (index, 1992=100). This is our measure of price level.

FYFF: Federal funds rate per annum.

We define consumption c as (GCNQF+GCSQF+GCDQF)/P16, investment inv as GIFQF/P16, government spending g as GGEQF/P16, output y as $c+g+inv$, employment n as LHEM/P16, hours per worker h as LW, interest rate i as FYFF, money stock m as M1/P16 and we used the total factor productivity series a constructed in the following way.

From section 2.9 we have:

$$Log(A_t^{tec}) = Log(y_t) - \theta Log(k_t) - (1-\theta) Log(h_t n_t)$$

We have quarterly series for all variables on the right hand side, except for capital. We used the quarterly series calculated in Castaneda [2001].[19]

B Artificial Data

We generated artificial data of the same length for each one of the above historical variables. These was done by simulating the model when the economy is subject simultaneously to the three different shocks. Each one of this is assumed to be generated by independent AR(1) processes as described in section 2.6, 2.7 and 2.9. In order to avoid dependence on initial conditions, we simulated series of length 1000 plus the length of historical data (134) and got rid of the first 1000 periods.

[19] His estimation is based on the method by Chow and Lin [1971]. The basic idea is to regress a yearly series on capital, output, investment and private depreciation, and then to use quarterly series for all the above (except capital) to back up information for capital on a quarterly basis. I thank Juan Carlos Castaneda for kindly providing me with this series.

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