INTERTEMPORAL DISTURBANCES

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Abstract. Disturbances affecting agents' intertemporal substitution are the key driving force of macroeconomic fluctuations. We reach this conclusion exploiting the asset pricing implications of an estimated general equilibrium model of the U.S. business cycle with a rich set of real and nominal frictions.

1. Introduction

Macroeconomic models imply two broad classes of optimization conditions. On the one hand, the *intratemporal* first order conditions equate the marginal rate of substitution (MRS) between two goods consumed *at the same time* to their relative price and, through this, to the marginal rate of transformation (MRT). On the other hand, the *intertemporal* first order conditions equate the MRS of the same good *across time* to the relative price and the MRT.

This distinction is useful to state clearly the most important conclusion of this paper. The key source of macroeconomic fluctuations are shocks that directly perturb the intertemporal first order conditions of the agents' optimization problems, i.e. shocks perturbing the allocation of resources

Date: October 2005. We are grateful to Larry Christiano for many useful conversations and to participants to the 2005 annual meeting of the Society for Economic Dynamics and the Cleveland Fed conference on "Empirical methods and applications for DSGE and factor models" (in particular Ricardo Reis, our discussant) for comments. Special thanks to Alejandro Justiniano for many discussions and for sharing his codes for the estimation of DSGE models. The views expressed in the paper are those of the authors and are not necessarily reflective of views at the Federal Reserve Bank of New York or the Federal Reserve System.

across time. We label these shocks *intertemporal disturbances*, to distinguish them from the *intratemporal disturbances*, which perturb instead the intratemporal first order conditions of the agents' maximization problems.[1]

We can interpret these disturbances in several different ways. In most DSGE modelling, they are interpreted as structural features of the economic environment, as genuinely exogenous shifts in tastes, technology or policies. Others (see, for instance, Mulligan (2002c) or Chari, Kehoe, and McGrattan (2005)) prefer to think of them as reduced form representations of underlying economic frictions, wedges or, in general, features of the economy we wish to abstract from. Finally, a related way of interpreting these disturbances is as convenient statistical representations of model misspecification, a measure of the extent to which our problem's first order conditions are not satisfied in the data. This interpretation is particularly appropriate if the model's fit is inferior to that of careful statistical representations of the data, as is the case even for state-of-the-art DSGE models (Del Negro, Schorfheide, Smets, and Wouters (2004)). Therefore, the finding that intertemporal disturbances are paramount leads us to conclude that more effort should be directed towards understanding agents' intertemporal choices.

Another important implication of our analysis is that models in which the intertemporal substitution of consumption and investment are at the core of the monetary transmission mechanism might be unreliable as tools for monetary policy analysis. In fact, the statistical and economic relevance of the intertemporal disturbances in our framework is consistent with important omissions in the model's structural representation of the relationship between interest rates and real variables. This is not necessarily a concern for the purpose of monetary policy analysis, if these disturbances are stand-ins for features of the economy that are not related to the transmission of policy shocks. However, there are good reasons to think that this is unlikely. For example, according to the so-called "credit view" of business cycles, financial market frictions play a key role in the propagation of shocks, including

[1] This distinction is not necessarily a partition. Some shocks can perturb both the intratemporal and the intertemporal first order conditions.

those to monetary policy (see Bernanke, Gertler, and Gilchrist (1999) for a survey and a prototypical DSGE model and Christiano, Gust, and Roldos (2004) and Iacoviello (2005) for more recent contributions along similar lines). These frictions imply the same kind of wedges in the Euler equations for consumption and/or investment stressed by our paper. Models that abstract from these frictions might therefore paint a misleading picture of the effects of monetary policy on the economy.

Our results are quite surprising, when considered through the lens of macroeconomics. For example, Hall (1997) found that most of the movements in employment over the business cycle are due to intratemporal "preference" shocks. Hall's (1997) results have been confirmed and expanded upon by Mulligan (2002b), Mulligan (2002c) and Chari, Kehoe, and McGrattan (2005). Chari, Kehoe, and McGrattan (2005) in particular find that intertemporal shocks, or investment wedges in their accounting taxonomy, are a negligible source of business cycle fluctuations. This is true for the entire postwar sample, as well as more specifically during the Great Depression and the 1982 recession.

What is the source of the discrepancy between our results and those in the literature? We argue that the conclusion that intertemporal disturbances are unimportant is an artefact of the common practice of disregarding asset market data in macroeconomics. In fact, instead of using market measures of asset returns, the macroeconomic studies mentioned above measure the real rate of return on capital by its marginal product (MPK). In other words, by focusing on a planner's problem, they directly equate marginal rates of substitution across time to marginal rates of transformation, ignoring their link through relative prices. In a competitive equilibrium, these differences in measurement should not matter. In the data, however, there is a significant discrepancy between market measures of asset returns and the marginal product of capital, as also emphasized by Mulligan (2002a). In practice, this discrepancy has a dramatic impact on the empirical performance of the Euler equation. Indeed, the consumption Euler equation performs reasonably well when returns are measured by the MPK, but very poorly when returns are measured using asset market data (Hall (1988), Campbell (2003), Mulligan (2002a) and Mulligan (2004)).

One possible reaction to this finding is simply to de-emphasize the asset pricing implications of macro models, and focus instead on their success with quantities. This approach is well established in macroeconomics, and has proved fruitful in addressing many interesting questions. However, we find it unsatisfactory, for at least two reasons. First, in a decentralized equilibrium, prices are the signals that lead agents to align marginal rates of substitution and transformation. Models that achieve the correct alignment of those rates, but with the wrong prices, should at least be "puzzling." Trying to solve this puzzle is a challenge squarely within the realm of macroeconomics, as forcefully argued by Cochrane (2005).[2] Second, and most importantly for our purposes, disregarding asset prices is not a viable approach, if we are interested in modeling the short-term nominal interest rate as the main instrument of monetary policy.

Although in contrast with the macroeconomic tradition, our results are consistent with a long line of research in finance, dating back at least to Hansen and Singleton's (1982 and 1983) seminal studies on the GMM estimation of Euler equations. This literature had varying degrees of success in recovering "reasonable" estimates of taste parameters.[3] However, one result is remarkably robust across all these studies. The overidentifying restrictions embedded in the Euler equation are consistently and overwhelmingly rejected. This clearly points to a severe misspecification of the first order condition for intertemporal optimization, the same kind of misspecification suggested by the importance of intertemporal disturbances in our framework.

[2] A possible solution to the "puzzle" lies in the observation that prices might not be allocative. This is plausible in the case of wages, much less so in reference to asset prices.

[3] For example, Eichenbaum, Hansen, and Singleton (1988) and Mankiw, Rotemberg, and Summers (1985) reach opposite conclusions about the implications of their parameter estimates for the plausibility of the implied utility function.

Our work complements the findings of the finance literature and extends them in one important direction. In fact, not only do we document the empirical failures of the model's Euler equations, but we also show that these failures account for a very large portion of U.S. output, investment, hours and consumption fluctuations. In other words, by embedding the Euler equations into a general equilibrium framework, we can measure the economic importance of the shocks perturbing the model's asset pricing moment conditions. The economic importance of these shocks cannot be assessed using the approach of the finance literature dedicated to testing Euler equations in a partial equilibrium setting.

The paper is organized as follows. Section 2 presents the main intuition behind our conclusions, in the context of a stylized model. Section 3 introduces a more realistic model that we use for the estimation. Section 4 presents the estimation results. Section 5 concludes.

2. The Importance of Intertemporal Disturbances

This section presents a very stylized general equilibrium model, which is helpful in illustrating the intuition behind our main results.

Consider the problem of a representative household maximizing the familiar utility function, which depends on consumption (C) and hours worked (L):

$$E_t \sum_{s=0}^{\infty} \beta^s b_{t+s} \left[\frac{C_{t+s}^{1-\theta}}{1-\theta} - \frac{L_{t+s}^{1+\nu}}{1+\nu} \right].$$

In this formulation, b_t is an exogenous shock to the consumer's impatience, which affects both the marginal utility of consumption and the marginal disutility of labor. The household owns the firms and the capital stock. Therefore, the budget constraint is given by

$$C_{t+s}+T_{t+s}+I_{t+s}+B_{t+s} \leq (1+r_{t+s-1})\, B_{t+s-1}+\Pi_{t+s}+w_{t+s}L_{t+s}+r_{t+s}^{k}K_{t+s},$$

where T_t represents lump-sum tax payments, I_t is investment, B_t is holding of government bonds, r_t is the risk-free real interest rate, Π_t is the profit earned from the ownership of the firms and w_t are real wages. Capital, denoted by K_t, is rented to firms at the rate r_t^k. Households accumulate the capital stock through investment, according to the equation

$$K_{t+1} = (1-\delta)K_t + \mu_t I_t,$$

where δ denotes the capital depreciation rate and μ_t is a random disturbance affecting the efficiency of producing capital goods, as in Greenwood, Hercowitz, and Krusell (1997) or Fisher (2005). In a competitive equilibrium, the investment specific technology shock μ_t is also equal to the inverse of the relative price of investment to consumption goods.

In this economy, firms operate a Cobb-Douglas production function in capital and hours. They maximize profits, operating in perfectly competitive markets. The model is closed by a Government, which finances its budget deficit by issuing short term bonds.

Focusing on the intertemporal first order conditions of the consumer problem, we have

$$1 = E_t\left[M_{t+1}\left(1+r_t\right)\right] \tag{2.1}$$

$$1 = E_t\left[M_{t+1}\mu_t\left(r_{t+1}^k + \frac{1-\delta}{\mu_{t+1}}\right)\right] \tag{2.2}$$

$$M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\theta}\frac{b_{t+1}}{b_t} \tag{2.3}$$

Equations (2.1) and (2.2) can be interpreted as pricing equations for the risk-free bond and the capital stock respectively. M_{t+1} is the model's stochastic discount factor, which fluctuates endogenously with consumption, and exogenously with the taste disturbance b_t. The investment specific shock μ_t is a shock to the return on capital. Both disturbances perturb the model's Euler equations and, therefore, can be thought of as intertemporal disturbances. When estimated, they can be interpreted as quantifying the empirical failures of the Euler equations, the extent to which empirical discounted returns do not equal one.

Why are our results about the importance of these intertemporal disturbances so different from those in the macro literature?

The key to answering this questions is the observation that equation (2.2) performs quite well when the rental rate is measured by the marginal product of capital, as it should be in a planner's problem. Intuitively, this reflects the fact that the volatility of consumption growth and of the marginal product of capital are not too far from each other. More specifically, Mulligan (2002a) and Mulligan (2004) show that estimates of θ obtained using equation (2.2) are close to unity. In other words, for a researcher concentrating on equation (2.2), and ignoring equation (2.1), as in a model in which capital is the only asset, it would be natural to conclude that "big" intertemporal disturbances are not necessary to fit the data. This is consistent with the results of Hall (1997) and Chari, Kehoe, and McGrattan (2005).

But this is not the end of the story. To understand the loss of information and the consequences of disregarding equation (2.1) and, therefore, the asset pricing implications of our model, figure 1 compares data on the marginal product of capital to a market measure of the risk-free real interest rate, constructed by subtracting expected inflation from the 3-month Treasury Bills rate.[4] The differences between the time series of the marginal product of capital and the market-based measures of the rate of return are evident. Means and volatilities are very far apart. Moreover, it is hard to see any positive comovement. Given these enormous differences, it should not be surprising that using different measures of the real interest rate might lead to a very different degree of success in fitting an Euler equation.

Indeed, a very large literature has stressed that, without the shock b_t, equation (2.1) performs rather poorly when confronted with the data (see Singleton (1990) for a survey). This is true even under much more general specifications for M_{t+1} than the one adopted here (Eichenbaum, Hansen, and Singleton (1988)). In particular, equation (2.1) is resoundingly rejected by tests of overidentifying restrictions, no matter what the utility specification,

[4] The inflation rate averaged over the last four quarters is used as a proxy for expected inflation. Following Hall (1997) and Chari, Kehoe, and McGrattan (2005), the MPK is constructed using data on investment and the capital accumulation equation to derive the capital stock.

the measure of the interest rate, the list of instruments, or the frequency of the observations.

This should suggest that looking at equations (2.1) and (2.2) jointly leads to a very different conclusion about the size and the importance of intertemporal disturbances, which are crucial in our DSGE model. In fact, the model's discount factor prices short-term bonds correctly, but only thanks to exogenous movements in b_t. As a consequence, this same discount factor is unlikely to also price the capital stock, since b_t increases its volatility above that of the marginal product of capital. Moreover, we know from Mulligan (2002a) and Mulligan (2004) that the capital stock is in fact priced reasonably well by consumption growth alone. Hence the importance of the other intertemporal shock μ_t, to realign the return on capital with the discount factor needed to fit equation (2.1).

This section illustrated how the unimportance of intertemporal shocks often observed in macroeconomics might be an artefact of concentrating on models in which capital is the only asset, equation (2.2) is the only Euler equation, and in which, therefore, the pricing of other assets is ignored. In fact, in the case of a small monetary model without investment dynamics analyzed in section 4.1, in which output is equal to consumption and equation (2.1) is the only Euler equation, output fluctuations are mostly explained by intertemporal shocks. In the more realistic case of a model with capital and, therefore, both Euler equations, we will show that paying attention to asset prices is a necessary, although not sufficient, condition for reversing the relative importance of intertemporal and intratemporal shocks as engines of the business cycle. In fact, in such a model, intertemporal disturbances have an enormous impact on investment and consumption fluctuations. However, they are not propagated to output and hours unless the model is enriched with a number of frictions. The reason is that, with no frictions, investment and consumption move in opposite directions in response to intertemporal disturbances. Real frictions help to reduce this negative conditional correlation, thus generating a more plausible transmission mechanism for intertemporal shocks. A more careful discussion of these issues is postponed until section 4.3.

3. A model of the US business cycle

This section presents the empirical model that will be used for the estimation and to document the quantitative importance of the points made in section 2. As a baseline specification, we use a relatively large-scale model of the business cycle, with a number of nominal and real frictions, similar to that of Christiano, Eichenbaum, and Evans (2005). In this model, the presence of habit formation in consumption and adjustment costs in investment makes the representation of the Euler equations equivalent to (2.1) and (2.2) slightly more complex than in section 2. This version of the model has been shown to fit U.S. data nearly as well as Bayesian vector autoregressions (Smets and Wouters (2003)).

Following most of the literature, but differently from Chari, Kehoe, and McGrattan (2005), in our model exogenous disturbances are assumed to be uncorrelated. Clearly, this assumption imposes additional restrictions, but is needed in order to guarantee any meaningful structural interpretation for the shocks.

Our brief illustration of the model follows closely Del Negro, Schorfheide, Smets, and Wouters (2004).

3.1. **Final goods producers.** At every point in time t, perfectly competitive firms produce the final consumption good Y_t, using the intermediate goods $Y_t(i)$, $i \in [0,1]$ and the production technology

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{1}{1+\lambda_{p,t}}} di \right]^{1+\lambda_{p,t}} .$$

$\lambda_{p,t}$ follows the exogenous stochastic process

$$\log \lambda_{p,t} = (1-\rho_p) \log \lambda_p + \rho_p \log \lambda_{p,t-1} + \varepsilon_{p,t},$$

where $\varepsilon_{p,t}$ is $i.i.d.N(0, \sigma_p^2)$. Profit maximization and zero profit condition for the final goods producers imply the following relation between the price of the final good (P_t) and the prices of the intermediate goods ($P_t(i)$)

$$P_t = \left[\int_0^1 P_t(i)^{\frac{1}{\lambda_{p,t}}} di \right]^{\lambda_{p,t}},$$

and the following demand function for the intermediate good i:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t.$$

3.2. **Intermediate goods producers.** A monopolist firm produces the intermediate good i using the following production function:

$$Y_t(i) = \max \left\{ A_t^{1-\alpha} K_t(i)^\alpha L_t(i)^{1-\alpha} - A_t F; 0 \right\},$$

where, as usual, $K_t(i)$ and $L_t(i)$ denote respectively the capital and labor input for the production of good i, F represents a fixed cost of production and A_t is an exogenous stochastic process capturing the effects of technology. In particular, we model A_t as a unit root process, with a growth rate ($z_t \equiv \log \frac{A_t}{A_{t-1}}$) that follows the exogenous process

$$z_t = (1 - \rho_z)\gamma + \rho_p z_{t-1} + \varepsilon_{z,t},$$

where $\varepsilon_{z,t}$ is $i.i.d.N(0, \sigma_z^2)$. As in Calvo (1983), a fraction ξ_p of firms cannot re-optimize their prices and, therefore, set their prices following the indexation rule

$$P_t(i) = P_{t-1}(i) \pi_{t-1}^{\iota_p} \pi^{1-\iota_p},$$

where π_t is defined as $\frac{P_t}{P_{t-1}}$ and π denotes the steady state value of π_t. Subject to the usual cost minimization condition, re-optimizing firms choose their price ($\tilde{P}_t(i)$) by maximizing the present value of future profits

$$E_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \lambda_{t+s} \left\{ \left[\tilde{P}_t(i) \left(\Pi_{j=0}^s \pi_{t-1+j}^{\iota_p} \pi^{1-\iota_p} \right) \right] Y_{t+s}(i) - \left[W_t L_t(i) + r_t^k K_t(i) \right] \right\},$$

where λ_{t+s} is the marginal utility of consumption, W_t and r_t^k denote respectively the wage and the rental cost of capital.

3.3. **Households.** The firms are owned by a continuum of households, indexed by $j \in [0,1]$. As in Erceg, Henderson, and Levin (2000), while each household is a monopolistic supplier of specialized labor ($L_t(j)$), a number of 'employment agencies' combines households' specialized labor into labor services available to the intermediate firms

$$L_t = \left[\int_0^1 L_t(j)^{\frac{1}{1+\lambda_w}} dj\right]^{1+\lambda_w}.$$

Profit maximization and zero profit condition for the perfectly competitive employment agencies imply the following relation between the wage paid by the intermediate firms and the wage received by the supplier of specialized labor $L_t(j)$

$$W_t = \left[\int_0^1 W_t(j)^{\frac{1}{\lambda_w}} dj\right]^{\lambda_w},$$

and the following labor demand function for labor type j:

$$L_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\frac{1+\lambda_w}{\lambda_w}} L_t.$$

Each household maximizes the utility function[5]

$$E_t \sum_{s=0}^{\infty} \beta^s b_{t+s}\left[\log\left(C_{t+s}(j) - hC_{t+s-1}(j)\right) - \varphi_{t+s}\frac{L_{t+s}(j)^{1+\nu}}{1+\nu}\right],$$

where $C_t(j)$ is consumption, h is the "degree" of habit formation, φ_t is a preference shock that affects the marginal disutility of labor and b_t is a "discount factor" shock affecting both the marginal utility of consumption and the marginal disutility of labor. These two shocks follow the stochastic processes

$$\begin{aligned} \log b_t &= \rho_b \log b_{t-1} + \varepsilon_{b,t} \\ \log \varphi_t &= (1-\rho_\varphi)\log\varphi + \rho_\varphi \log \varphi_{t-1} + \varepsilon_{\varphi,t}. \end{aligned}$$

Notice also that, following the real business cycle tradition, in order to ensure the presence of a balanced growth path, we work with log utility. The household budget constraint is given by

$$P_{t+s}C_{t+s}(j) + P_{t+s}I_{t+s}(j) + B_{t+s}(j) \leq R_{t+s-1}B_{t+s-1}(j) + Q_{t+s-1}(j) +$$

[5] We assume a cashless limit economy as described in Woodford (2003).

$+\Pi_{t+s}+W_{t+s}(j)L_{t+s}(j)+r^k_{t+s}(j)u_{t+s}(j)\bar{K}_{t+s-1}(j)-P_{t+s}a(u_{t+s}(j))\bar{K}_{t+s-1}(j),$

where $I_t(j)$ is investment, $B_t(j)$ is holding of government bonds, R_t is the gross nominal interest rate, $Q_t(j)$ is the net cash flow from participating in state contingent securities, Π_t is the per-capita profit that households get from owning the firms. Households own capital and choose the capital utilization rate which transform physical capital ($\bar{K}_t(j)$) in effective capital

$$K_t(j) = u_t(j)\bar{K}_{t-1}(j),$$

which is rented to firms at the rate $r^k_t(j)$. The cost of capital utilization is $a(u_{t+s}(j))$ per unit of physical capital. As in Altig, Christiano, Eichenbaum, and Linde (2005), we assume that $u_t = 1$ and $a(u_t) = 0$ in steady state. The usual physical capital accumulation equation is described by

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

where δ denotes the depreciation rate and, as in Christiano, Eichenbaum, and Evans (2005) and Altig, Christiano, Eichenbaum, and Linde (2005), the function S captures the presence of adjustment costs in investment, with $S' = 0$ and $S'' > 0$ in steady state.[6] μ_t is a random shock to the price of investment relative to consumption and follows the exogenous process

$$\log\mu_t = \rho_\mu \log\mu_{t-1} + \varepsilon_{\mu,t}.$$

As in Erceg, Henderson, and Levin (2000), a fraction ξ_w of households cannot re-optimize their wages and, therefore, set their wages following the indexation rule

$$W_t(j) = W_{t-1}(j)\left(\pi_{t-1}e^{z_{t-1}}\right)^{\iota_w}\left(\pi e^{\gamma}\right)^{1-\iota_w}.$$

The remaining fraction of re-optimizing households set their wages by maximizing

$$E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s b_{t+s}\left\{-\varphi_{t+s}\frac{L_{t+s}(j)^{1+\nu}}{1+\nu}\right\},$$

subject to the labor demand function.

[6] Lucca (2005) shows that this formulation of the adjustment cost function is equivalent (up to a first order approximation of the model) to a generalization of a time to build assumption.

3.4. **Monetary and Government Policies.** Monetary policy sets short term nominal interest rates following a Taylor type rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{Y_t}{A_t}\right)^{\phi_Y}\right]^{1-\rho_R} e^{\varepsilon_{MP,t}},$$

where R is the steady state for the nominal interest rate and $\varepsilon_{MP,t}$ is an $i.i.d.N(0, \sigma_R^2)$ monetary policy shock.

Fiscal policy is assumed to be fully Ricardian, with the Government financing its budget deficit by issuing short term bonds. Public spending is given by

$$G_t = \left(1 - \frac{1}{g_t}\right) Y_t,$$

where g_t is an exogenous disturbance following the stochastic process

$$\log g_t = (1 - \rho_g) \log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}.$$

3.5. **Market Clearing.** The resource constraint is given by

$$C_t + I_t + G_t + a(u_t)\bar{K}_{t-1} = Y_t,$$

3.6. **Steady State and Model Solution.** Since the technology process A_t is assumed to have a unit root, consumption, investment, capital, real wages and output evolve along a stochastic growth path. Once the model is rewritten in terms of detrended variables, we can compute the non-stochastic steady state and loglinearly approximate the model around the steady state.

We conclude the discussion of the model by specifying the vector of observables, completing the state space representation of our model:

$$[\Delta \log Y_t, \Delta \log C_t, \Delta \log I_t, \log L_t, \Delta \log \frac{W_t}{P_t}, \pi_t, R_t], \tag{3.1}$$

where $\Delta \log X_t$ denotes $\log X_t - \log X_{t-1}$. A description of the data series that we use for the estimation can be found in appendix A.

3.7. **Bayesian inference and priors.** Bayesian methods are used to characterize the posterior distribution of the structural parameters of the models (see An and Schorfheide (2005) for a survey). The posterior distribution combines the likelihood and the prior information. In the rest of this subsection we detail the assumptions about the prior.

We fix a small number of the model parameters to values commonly used in the existing literature. In particular, we set the steady state share of capital income (α) to $\frac{1}{3}$, the quarterly depreciation rate of capital (δ) to 0.025 and the steady state government spending to GDP ratio ($1 - 1/g$) to 0.22, which corresponds to the average value of G_t/Y_t in our sample.

Table 1 reports our priors for the remaining parameters of the model. These priors are relatively disperse and reflect previous studies and results in the literature (see, for instance, Altig, Christiano, Eichenbaum, and Linde (2005), Del Negro, Schorfheide, Smets, and Wouters (2004) or Levin, Onatski, Williams, and Williams (2005)).

4. Empirical results

This section estimates two versions of the model of section 3. The objective is showing how intertemporal disturbances are important both for the fit of the models and for the explanation of macroeconomic fluctuations.

4.1. **Empirical results based on a New-Keynesian model.**

The new-Keynesian model can be thought of as a simplified version of the model of section 3. In particular, we assume that the share of capital in the production function of the intermediate firms is equal to zero, resulting in a model without capital and investment dynamics. Therefore, this model includes only one of the two Euler equations of section 2, equation (2.1).

To compare our results with the new-Keynesian literature, we estimate the model using only data on output, inflation and the short-term nominal interest rate. Consequently, we consider only a subset (four) of the shocks presented in the fully-fledged model: technology (z_t), monetary policy (ε_t^{MP}), mark-up[7] ($\lambda_{p,t}$) and discount factor shock (b_t). Table 2 reports posterior medians, standard deviations and 90 percent posterior intervals for the coefficients that we are able to identify in this small model. The estimates of the coefficients are reasonable and in line with previous results in the literature (see, for instance, Ireland (2004)). In particular, observe

[7] Notice that the mark-up shock is not separately identified from the intratemporal taste shock (φ_t) in this version of the model.

the high estimate of the price stickiness parameter (ξ_p), which has been criticized for being in contrast with the micro evidence on price rigidity (Bils and Klenow (2004)).[8]

The introduction of the discount factor shock (b_t) makes our results interesting in several respects. First, the fit of the model improves drastically with respect to the case without the discount factor shock. The log marginal data density of the baseline model equals -872.64, while it decreases to -914.03 for the specification with a constant discount factor, implying huge posterior odds in favor of the baseline model.

Second, the shock to the stochastic discount factor explains 75 percent of the unconditional variance of GDP growth, as shown in table 3. This number seems very high, especially when compared to the share of variance attributable to technology shocks (23 percent) and monetary policy shocks (only 2 percent).[9]

Summarizing, from this estimation exercise we draw the main conclusions that the intertemporal disturbance (in this version of the model, the shock to the discount factor, b_t) plays a crucial role. In fact, not only it improves the fit of the model dramatically, but it also explains most of output fluctuations.

4.2. **Empirical results based on the fully-fledged model.** In this subsection we turn to the estimation of the fully-fledged model presented in section 3.

Table 4 presents posterior medians, standard deviations and 90 percent posterior intervals for the estimated coefficients of this model. Notice that the estimates are reasonable and in line with values obtained by previous studies (Altig, Christiano, Eichenbaum, and Linde (2005), Del Negro, Schorfheide, Smets, and Wouters (2004), Levin, Onatski, Williams, and Williams (2005)). Once again, particularly interesting is table 5, reporting the variance decomposition exercise for the fully-fledged model. A couple of

[8] However, indexation makes the results consistent with the micro evidence on the high frequency of price changes, since it implies that prices change every period.

[9] A similar result on the importance of the b_t shock is obtained by Justiniano and Preston (2005) in an open economy framework.

points deserve particular attention. First, the disturbance to the stochastic discount factor is the most important shock in explaining consumption fluctuations. In fact, the b_t shock accounts alone for almost 50 percent of the variance of consumption growth. The important role of the preference shock b_t is even more surprising in light of the fact that the estimated model exhibits habit formation in consumption. This feature helps explain the observed persistence in consumption, mitigating the failure of the Euler equation. However, the introduction of habits also generates a higher variability of the risk-free rate, which in some case exceeds the one observed in the data (see, for instance, the discussion in Boldrin, Christiano, and Fisher (2001) or Campbell and Cochrane (1999)). This might also explain the importance of b_t in our framework, although this issue deserves further investigation.

The second important thing is that the other intertemporal disturbance, the shock to the relative price of investment goods, μ_t,is by far the most important shock in explaining not only investment, but also hours and output fluctuations. This disturbance explains about 60 percent of the variability of investment growth, 57 percent of the variability of hours worked and 40 percent of the variability of output growth. Neutral technology shocks account only for one forth of the variance of GDP growth and 12 and 15 percent of the variance of hours and investment growth respectively. Moreover, once again, monetary policy shocks do not seem a very important source of fluctuations, accounting for only 5 percent of the variance of GDP.

While it might seem surprising, this result is in line with the recent evidence presented in Fisher (2005), Justiniano and Primiceri (2005), Gali (1999), Christiano, Eichenbaum, and Vigfusson (2004) and Francis and Ramey (2005a and b). In particular, Justiniano and Primiceri (2005) use a similar model and provide convincing evidence that the shock to the relative price of investment plays a prominent role in explaining the reduction in the volatility of U.S. GDP that has characterized the last twenty years.

In summary, the estimation of the fully-fledged model confirms the intuition provided in section 2 and the results based on the model without investment dynamics of the previous subsection. Intertemporal disturbances, such as shocks to the stochastic discount factor or the relative price of investment goods, play a crucial role in business cycle models, since they account for a very large portion of the fluctuations of consumption, investment, hours and output.

As mentioned earlier, our conclusion differs importantly from that of previous macroeconomic studies. The intuition explaining this discrepancy was illustrated in section 2. Here we want to observe that our findings diminish, but do not undermine, the importance of *intratemporal* shocks, such as the "labor wedge" emphasized by Hall (1997), Mulligan (2002b), Gali, Gertler, and Lopez-Salido (2003) or Chari, Kehoe, and McGrattan (2005). Indeed, our intratemporal taste shock (φ_t) explains a sizable portion of the variability of hours and, especially, real wages, as shown in table 5. However, in this paper we want to draw attention to the fact that *intertemporal* disturbances are even more important to understand macroeconomic fluctuations and the dimensions of misspecification of a large class of dynamic models.

4.3. **Assessing the role of frictions and asset prices.** What features of the fully-fledged model are responsible for amplifying the role of intertemporal shocks as a source of fluctuations? In section 2 we argued that the main difference between an RBC model with wedges and our fully-fledged model is the fact that the latter includes a pricing equation for a short-term nominal bond. However, this is not the only difference between the two models. In fact, the fully-fledged model includes a host of real and nominal frictions, like sticky wages, variable capital utilization, adjustment costs in investment and habit formation in consumption. All these frictions modify the model's representation of the relevant margins for intertemporal substitution. They could therefore play an important role in shifting the main source of fluctuations from intratemporal to intertemporal shocks. To asses the relative contribution of different frictions to this shift, this section compares the variance decomposition of the baseline model to that of a prototypical real model and of two intermediate specifications.

4.3.1. *A prototypical growth model.* The real model we consider is the stochastic growth core of the model of section 3. This is obtained by assuming perfectly flexible prices and wages, no habit in consumption, a fixed capital utilization rate and no adjustment costs in investment. The shocks we consider in this case are the neutral and investment specific technology shocks, z_t and μ_t, the intratemporal preference shock, φ_t and the government spending shock, g_t. This is similar to the specification adopted by Hall (1997) and Chari, Kehoe, and McGrattan (2005), and we follow them in including only output, consumption, investment and hours worked as observable variables in the estimation. The variance decomposition for this model is in table 6.

The results are in line with those of the previous macro literature. In particular, the fluctuations of output and the labor input are entirely explained by the intratemporal shocks. The neutral technology shock explains 60 percent of output variability, with the remainder almost exclusively due to the intratemporal preference shock, which also accounts for 95 percent of fluctuations in labor, an even more extreme result than Hall's (1997). Note, however, that the intertemporal shock (μ_t) does play a role in generating fluctuations in investment, and especially in consumption, even in this simple economy. This suggests that, although Mulligan (2002a) has shown that the standard Euler Equation prices capital better than bonds, its fit is still not perfect.[10]

What is interesting is that, in this prototypical growth model, the fluctuations in consumption and investment generated by the intertemporal shock offset each other, leaving no role for this shock to explain output. This is because embodied technological progress generates a negative conditional correlation between consumption and investment, which leaves output basically unchanged (this point is illustrated in figure 2, where we plot the

[10] In fact, Mulligan (2002a) shows that the standard consumption Euler equation correctly prices the after-tax return on capital. Our estimated intertemporal disturbance might therefore simply reflect the absence of taxes in our model.

impulse responses to the μ_t shock in the prototypical growth model). As a consequence, the likelihood would rather load on other shocks to generate business cycles, since consumption and investment are both procyclical.

4.3.2. *The role of real frictions.* Can real rigidities alone account for the paramount role of intertemporal disturbances in the fully-fledged model? The answer is no, as clearly illustrated by the results in table 7. Here we augment the prototypical growth model described above with all the real frictions also featured in the fully-fledged model. They are habit in consumption, variable capital utilization, investment adjustment costs and (real) wage rigidity.

The variance decomposition for this model is virtually identical to that of the previous model without frictions. Mechanically, the reason for the similarity of the results is that the posterior estimates of the parameters imply a small deviation from the frictionless model, with a limited degree of habit persistence, a very low investment adjustment costs and wage stickiness. This is because the main role of real rigidities is to generate a plausible transmission mechanism for intertemporal shocks, as we will see in more detail below. But in a model with no asset prices, such a mechanism is not needed, because intertemporal shocks can still be safely ignored when accounting for business cycles. We conclude that, from the vantage point of real models, intratemporal conditions are the ones requiring more work, as also suggested by Chari, Kehoe, and McGrattan (2005).

4.3.3. *The role of asset prices.* The next step is then to consider the effect of including the nominal interest rate among the observable variables. We do so by adding price stickiness to the stochastic growth model, or equivalently stripping the fully-fledged model of the consumption, investment and wages rigidities. Compared to the two real models described above, this specification has three more observables, price and wage inflation and nominal interest rates, and three more shocks, to monetary policy (ε_t^{MP}), the price mark-up ($\lambda_{p,t}$) and the discount factor (b_t). Of these changes, the most important for our purposes is the inclusion of the nominal interest rate among the observables, and of the corresponding Euler equation among the optimization conditions. This is the equation often tested, and overwhelmingly rejected, in the finance literature.

The decomposition of the sources of fluctuations in this model is presented in table 8. Two results stand out. First, the sum of the two intertemporal shocks now explains 82 and 61 percent of consumption and investment fluctuations respectively, almost twice as much as in the simple growth model. Moreover, 78 and 34 percent of the fluctuations in the nominal interest rate and inflation are due to those same shocks. Our empirical procedure can satisfy the model's restrictions imposed by the two Euler equations, in a way which is compatible with the observed evolution of the nominal interest rate, consumption and investment, only by loading significantly on both the intratemporal shocks. This is a fairly clear manifestation of the Euler equation's failure as a restriction on the returns measured in financial markets.

Nevertheless, the variability of output and labor remains an overwhelmingly intratemporal phenomenon. The effect of the intertemporal shocks is confined to fluctuations in consumption and investment, but these fluctuations still largely offset each other, resulting in virtually no movement in output and hours. In other words, asset prices bring to the fore some of the holes in the standard theory of intertemporal substitution. In our framework, these holes manifest themselves as intertemporal disturbances. However, the model's transmission mechanism is not rich enough to propagate these shocks from consumption and investment to hours and output. This propagation is achieved instead by the inclusion of real frictions, as illustrated by the variance decomposition for the fully-fledged model in table 5. Here, the intertemporal shocks together account for 41 percent of the fluctuations in output and 58 percent of those in labor, with the investment specific technology shock playing the key role.

The economic mechanisms behind this result are illustrated by the impulse responses in figure 3. As in all the models, an investment specific shock produces an investment boom. Without frictions, this is mostly financed by a reduction in consumption, with output almost unchanged. This is clearly not a business cycle (Greenwood, Hercowitz, and Krusell (2000) and Greenwood, Hercowitz, and Huffman (1988)). In the model with frictions, on the other hand, the investment boom is more gradual, due to the adjustment costs, and the reduction in consumption is kept in check by habits. At the same time, the sensitivity of the marginal utility of income to this change in consumption is high, amplifying the positive shift in labor supply. Moreover, the increase in demand triggered by the investment boom leads firms to hire more labor. And since wage stickiness flattens the labor supply curve, the result is a significant increase in hours. In addition, the drop in the relative price of new capital makes it optimal to increase the utilization rate, which further supports the increase in output. This in turn finances some of the increase in investment, relieving the pressure on consumption, which in fact turns positive approximately two years after the shock.

In sum, real and nominal frictions are complementary in attributing to intertemporal shocks a paramount role as sources of fluctuations. Including bond pricing among the criteria for judging a model's ability to fit the data is necessary to highlight the deficiencies of the standard theory of intertemporal substitution. These deficiencies manifest themselves as the shocks needed to explain investment and consumption fluctuations in the nominal model with no real rigidities. In this model, however, the intertemporal shocks are not viable sources of business cycle fluctuations, because they tend to move consumption and investment in opposite directions. The real frictions included in the fully-fledged model reduce significantly the negative comovement between consumption and investment, contributing to the transmission of those shocks to the rest of the economy. But the fully-fledged model is still not quite competitive in terms of fit with careful statistical representations of the data (Del Negro, Schorfheide, Smets, and Wouters (2004)). This suggests that the shocks that we identified as the main sources of business cycles still hide important unmodeled structural relationships. Our findings suggest that the next most fruitful modeling step should be towards improving our understanding of intertemporal choices.

5. Concluding remarks

> "If asset markets are screwed up, so is the equation of marginal rate of substitution and transformation in every macroeconomic model, so are those models' predictions for quantities, and so are their policy and welfare implications. Asset markets will have a greater impact on macroeconomics if their economic explanation *fails* than if it succeeds" (Cochrane (2005), p.3).

In this paper we follow Cochrane's (2005) advice, exploiting the (limited, but disastrous) asset pricing implications of a state-of-the-art model of the U.S. business cycle in order to shed light on the main sources of misspecification in modern macroeconomic models. In this way, we quantify the importance of *intertemporal disturbances*, i.e. the empirical failures of the intertemporal optimization conditions of DSGE models. Finally, we include these failures in a general equilibrium framework, showing that intertemporal disturbances cause a major portion of consumption, investment, labor and output fluctuations.

Appendix A. The Data

Our dataset spans a sample from 1954QIII to 2004QIV. All data are extracted from Haver Analytics database (series mnemonics in parenthesis). Following Del Negro, Schorfheide, Smets, and Wouters (2004), we construct real GDP by diving the nominal series (GDP) by population (LF and LH) and the GDP Deflator (JGDP). Real series for consumption and investment are obtained in the same manner, although consumption corresponds only to personal consumption expenditures of non-durables (CN) and services (CS), while investment is the sum of personal consumption expenditures of durables (CD) and gross private domestic investment (I). Real wages corresponds to nominal compensation per hour in the non-farm business sector (LXNFC) divided by the GDP deflator. Our measure of labor is given by the log of hours of all persons in non-farm business sector (HNFBN) divided by population. The quarterly log difference in the GDP deflator constitutes our measure of inflation, while for nominal interest rates we use the effective Federal Funds rate. We do not demean or detrend any series.

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Coefficient	Density	Mean	Stdev
ι_p	Beta	0.5	0.15
ι_w	Beta	0.5	0.15
γ	Normal	0.5	0.025
h	Beta	0.5	0.1
λ_p	Normal	0.15	0.05
λ_w	Normal	0.15	0.05
π	Normal	0.5	0.1
r	Normal	0.5	0.1
ν	Gamma	2	0.75
ξ_p	Beta	0.75	0.1
ξ_w	Beta	0.75	0.1
χ	Gamma	5	1
S''	Normal	4	1.5
ϕ_π	Normal	1.7	0.3
ϕ_y	Gamma	0.125	0.1
ρ_R	Beta	0.5	0.15
ρ_z	Beta	0.5	0.15
ρ_g	Beta	0.5	0.15
ρ_μ	Beta	0.5	0.15
ρ_{λ_p}	Beta	0.5	0.15
ρ_φ	Beta	0.5	0.15
ρ_b	Beta	0.5	0.15
σ_R	Inverse Gamma	0.15	0.15
σ_z	Inverse Gamma	0.15	0.15
σ_g	Inverse Gamma	0.15	0.15
σ_μ	Inverse Gamma	0.15	0.15
σ_{λ_p}	Inverse Gamma	0.15	0.15
σ_φ	Inverse Gamma	0.15	0.15
σ_b	Inverse Gamma	0.15	0.15

TABLE 1. Prior densities for the model coefficients

Coefficient	Median	Stdev	5^{th} pctile	95^{th} pctile
γ	0.495	0.022	0.46	0.533
π	0.627	0.083	0.488	0.757
r	0.538	0.078	0.422	0.675
λ_p	0.15	-	-	-
ν	2	-	-	-
h	0.654	0.069	0.534	0.762
ξ_p	0.886	0.044	0.805	0.95
ι_p	0.868	0.036	0.804	0.921
ϕ_π	1.229	0.168	1.02	1.565
ϕ_y	0.415	0.107	0.298	0.607
ρ_R	0.756	0.042	0.687	0.826
ρ_z	0.699	0.089	0.537	0.823
ρ_{λ_p}	0.094	0.037	0.044	0.164
ρ_b	0.677	0.08	0.532	0.796
σ_R	0.194	0.011	0.176	0.212
σ_z	0.324	0.082	0.206	0.476
σ_{l_p}	0.139	0.008	0.126	0.153
σ_b	0.576	0.201	0.387	1.081

Table 2. Posterior estimates for the coefficients of the New-Keynesyan model

	Shocks			
Variables	M.P. (ε_t^{MP})	tech. (z_t)	mark-up ($\lambda_{p,t}$)	inter.pref. (b_t)
$\Delta \log Y_t$	0.02	0.23	0.01	0.75
	[0.01;0.03]	[0.14;0.38]	[0;0.02]	[0.59;0.84]
π_t	0	0	1	0
	[0;0]	[0;0]	[0.99;1]	[0;0.01]
R_t	0.12	0	0.4	0.47
	[0.08;0.17]	[0;0.03]	[0.27;0.55]	[0.32;0.61]

TABLE 3. Variance decomposition for the New-Keynesian model (medians and 90 percent posterior intervals). Medians need not add up to exactly one

Coefficient	Median	Stdev	5^{th} percentile	95^{th} percentile
ι_p	0.165	0.067	0.081	0.296
ι_w	0.099	0.029	0.056	0.151
γ	0.423	0.024	0.382	0.46
h	0.815	0.026	0.767	0.853
λ_p	0.241	0.038	0.178	0.304
λ_w	0.138	0.037	0.081	0.201
π	0.564	0.099	0.398	0.722
r	1.021	0.08	0.887	1.154
ν	3.629	0.893	2.389	5.316
ξ_p	0.779	0.023	0.739	0.817
ξ_w	0.736	0.037	0.668	0.791
χ	7.284	1.082	5.644	9.219
S''	1.728	0.491	1.142	2.725
ϕ_π	2.043	0.142	1.842	2.305
ϕ_y	0.068	0.014	0.046	0.091
ρ_R	0.8	0.022	0.76	0.833
ρ_z	0.321	0.055	0.233	0.413
ρ_g	0.977	0.007	0.964	0.988
ρ_μ	0.924	0.024	0.877	0.956
ρ_{λ_p}	0.854	0.039	0.784	0.911
ρ_φ	0.494	0.07	0.372	0.607
ρ_b	0.832	0.039	0.766	0.894
σ_R	0.257	0.015	0.236	0.284
σ_z	1.168	0.066	1.071	1.287
σ_g	0.643	0.04	0.581	0.71
σ_μ	0.127	0.018	0.103	0.159
σ_{λ_p}	0.103	0.011	0.086	0.123
σ_φ	1.077	0.261	0.718	1.608
σ_b	0.569	0.139	0.399	0.856

TABLE 4. Posterior estimates for the coefficients of the fully-fledged model

	Shocks						
Variables	M.P. (ε_t^{MP})	tech. (z_t)	Gov. (g_t)	i. s. tech. (μ_t)	mark-up ($\lambda_{p,t}$)	intra.pref. (φ_t)	inter.pref. (b_t)
$\Delta \log Y_t$	0.05	0.25	0.08	0.4	0.12	0.07	0.01
	[0.03;0.07]	[0.18;0.33]	[0.07;0.11]	[0.29;0.53]	[0.07;0.17]	[0.04;0.11]	[0.01;0.02]
$\Delta \log C_t$	0.01	0.2	0.04	0.23	0.01	0.02	0.48
	[0;0.01]	[0.16;0.25]	[0.03;0.06]	[0.15;0.31]	[0.01;0.02]	[0.01;0.03]	[0.39;0.57]
$\Delta \log I_t$	0.04	0.15	0	0.61	0.1	0.05	0.04
	[0.02;0.06]	[0.1;0.22]	[0;0.01]	[0.47;0.75]	[0.05;0.15]	[0.03;0.09]	[0.02;0.06]
L_t	0.03	0.12	0.02	0.57	0.12	0.13	0.01
	[0.02;0.05]	[0.09;0.17]	[0.01;0.04]	[0.44;0.7]	[0.06;0.19]	[0.07;0.22]	[0;0.01]
$\Delta \log \frac{W_t}{P_t}$	0	0.31	0	0.07	0.18	0.43	0
	[0;0]	[0.24;0.39]	[0;0]	[0.04;0.12]	[0.14;0.24]	[0.36;0.49]	[0;0.01]
π_t	0.02	0.04	0.01	0.53	0.2	0.15	0.04
	[0.01;0.03]	[0.02;0.06]	[0;0.01]	[0.41;0.68]	[0.13;0.28]	[0.09;0.21]	[0.02;0.1]
R_t	0.1	0.03	0.01	0.62	0.07	0.08	0.06
	[0.07;0.15]	[0.02;0.06]	[0.01;0.02]	[0.5;0.73]	[0.05;0.11]	[0.05;0.12]	[0.03;0.12]

TABLE 5. Variance decomposition for the fully-fledged model (medians and 90 percent posterior intervals). Medians need not add up to exactly one

	Shocks			
Variables	tech. (z_t)	Gov. (g_t)	i.s. tech (μ_t)	intra.pref. (φ_t)
$\Delta \log Y_t$	0.60	0.01	0.02	0.37
$\Delta \log C_t$	0.26	0.13	0.58	0.04
$\Delta \log I_t$	0.23	0.23	0.29	0.25
L_t	0.01	0.01	0.04	0.95

TABLE 6. Variance decomposition for the prototypical stochastic growth model (medians). Medians need not add up to exactly one

	Shocks			
Variables	tech. (z_t)	Gov. (g_t)	i.s. tech (μ_t)	intra.pref. (φ_t)
$\Delta \log Y_t$	0.62	0.00	0.03	0.34
$\Delta \log C_t$	0.16	0.07	0.74	0.03
$\Delta \log I_t$	0.32	0.24	0.23	0.21
L_t	0.01	0.01	0.03	0.95

TABLE 7. Variance decomposition for the prototypical stochastic growth model with real frictions (medians). Medians need not add up to exactly one

	Shocks						
Variables	M.P. (ε_t^{MP})	tech. (z_t)	Gov. (g_t)	i.s. tech (μ_t)	mark-up $(\lambda_{p,t})$	intra.pref. (φ_t)	inter.pref. (b_t)
$\Delta \log Y_t$	0.01	0.54	0.01	0.04	0.04	0.31	0.05
$\Delta \log C_t$	0.00	0.09	0.06	0.37	0.01	0.02	0.45
$\Delta \log I_t$	0.01	0.12	0.12	0.28	0.04	0.10	0.33
L_t	0.00	0.01	0.01	0.02	0.02	0.90	0.04
$\Delta \log \frac{W_t}{P_t}$	0.15	0.39	0.00	0.01	0.37	0.07	0.01
π_t	0.53	0.07	0.01	0.30	0.01	0.05	0.04
R_t	0.00	0.13	0.02	0.71	0.02	0.06	0.07

TABLE 8. Variance decomposition for the stochastic growth model with nominal frictions (medians). Medians need not add up to exactly one

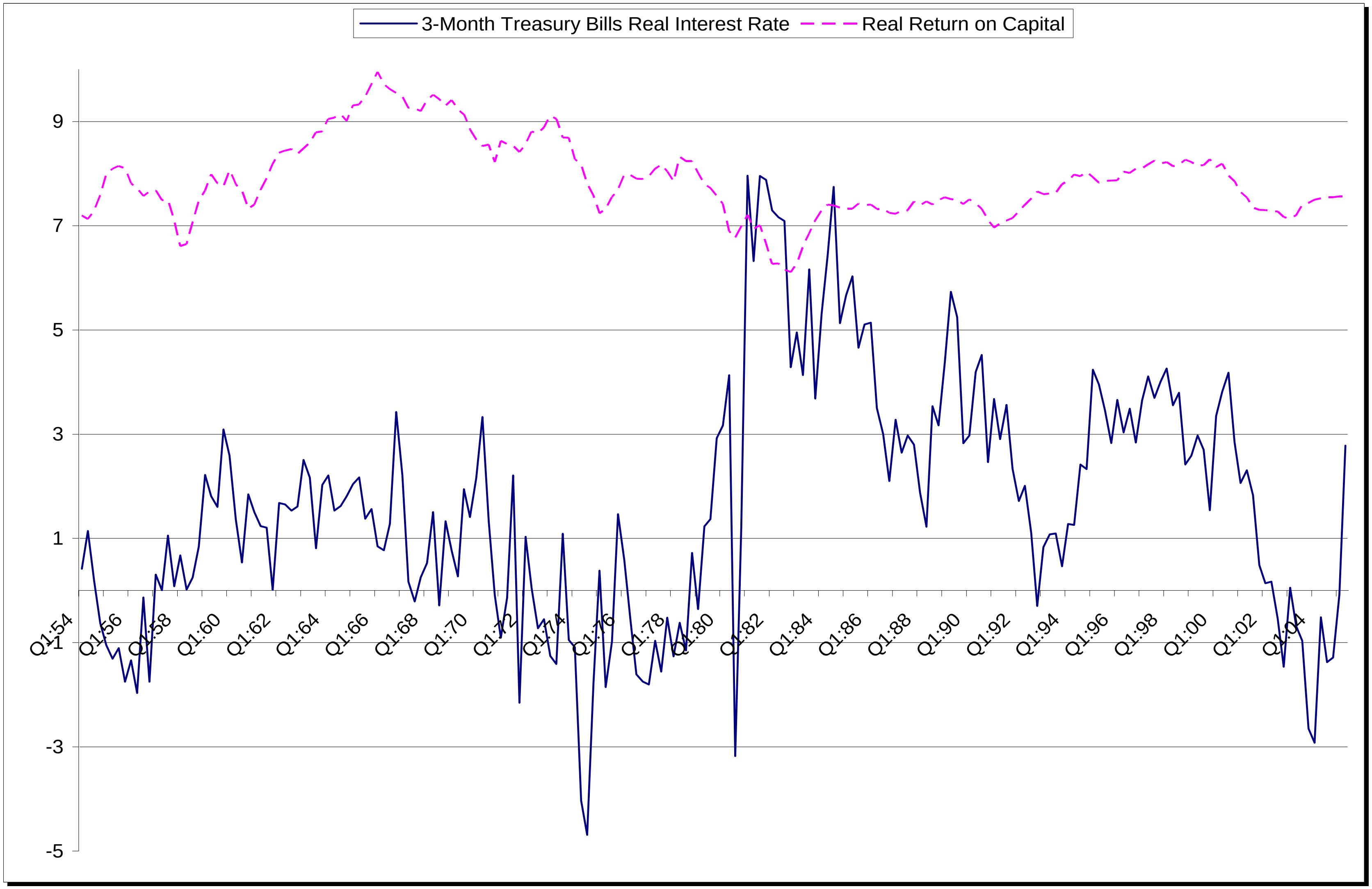

Figure 1: 3-month Treasury Bills real interest rate and real return on capital

FIGURE 2

Prototypical Growth Model:
Impulse responses to an investment specific technology shock

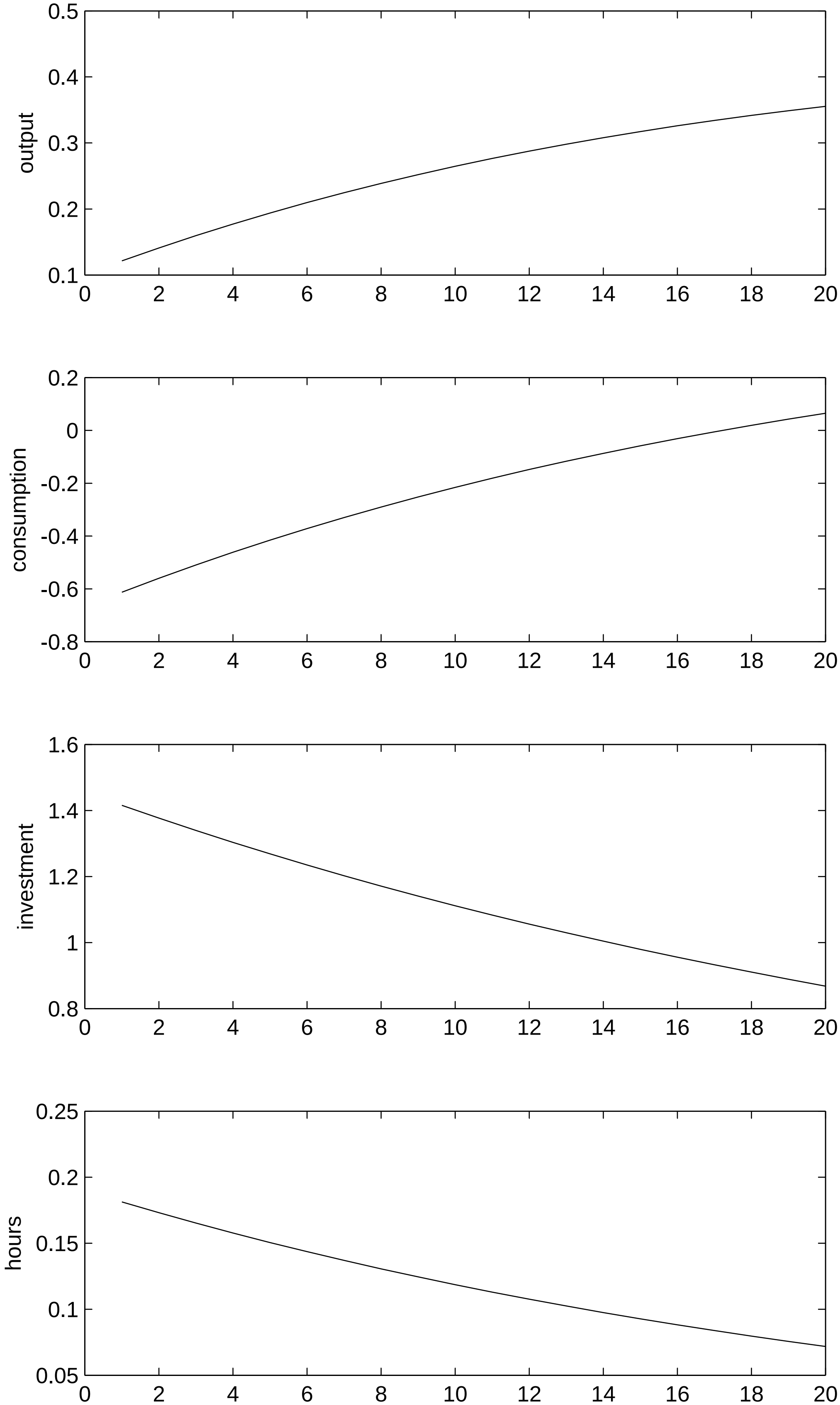

FIGURE 3

Fully-Fledged Model:
Impulse responses to an investment specific technology shock