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Nir Jaimovich
Sergio Rebelo

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ABSTRACT

Aggregate and sectoral comovement are central features of business cycle data. Therefore, the ability to generate comovement is a natural litmus test for macroeconomic models. But it is a test that most existing models fail. In this paper we propose a unified model that generates both aggregate and sectoral comovement in response to contemporaneous shocks and news shocks about fundamentals. The fundamentals that we consider are aggregate and sectoral TFP shocks as well as investment-specific technical change. The model has three key elements: variable capital utilization, adjustment costs to investment, and a new form of preferences that allow us to parameterize the strength of short-run wealth effects on the labor supply.

Nir Jaimovich
Department of Economics
579 Serra Mall
Stanford University
Stanford, CA 94305-6072
and NBER
njaimo@stanford.edu

Sergio Rebelo
Northwestern University
Kellogg School of Management
Department of Finance
Leverone Hall
Evanston, IL 60208-2001
and NBER
s-rebelo@northwestern.edu

1. Introduction

Business cycle data feature two important forms of comovement. The first is aggregate comovement: major macroeconomic aggregates, such as output, consumption, investment, hours worked, and the real wage tend to rise and fall together. The second is sectoral comovement: output, employment, and investment tend to rise and fall together in different sectors of the economy.

Lucas (1977) argues that these comovement properties reflect the central role that aggregate shocks play in driving business fluctuations. However, it is surprisingly difficult to generate both aggregate and sectoral comovement, even in models driven by aggregate shocks. Barro and King (1984) show that the one-sector growth model generates aggregate comovement only in the presence of contemporaneous shocks to total factor productivity (TFP). Other shocks generate a negative correlation between consumption and hours worked. Christiano and Fitzgerald (1998) show that a two-sector version of the neoclassical model driven by aggregate, contemporaneous TFP shocks does not generate sectoral comovement of investment and hours worked.

In this paper we propose a model that generates aggregate and sectoral comovement in response to both aggregate and sectoral shocks. The shocks that we consider are aggregate TFP shocks, investment-specific shocks, and sectoral TFP shocks to the consumption and investment sectors. We consider both contemporaneous shocks and news shocks. News shocks consist of information that is useful for predicting future fundamentals but does not affect current fundamentals.

The early literature on business cycles (e.g. Beveridge (1909), Pigou (1927), and Clark (1934)) emphasizes news shocks as potentially important drivers of business cycles. The idea is that news shocks change agents' expectations about the future, affecting their current investment, consumption, and work decisions. There is a revival of interest in this idea, motivated in part by the U.S. investment boom of the late 1990s and the subsequent economic slowdown. Figure 1 displays some suggestive data for this episode. The first panel shows data obtained from the Institutional Brokers Estimate System on the median analyst forecast of the value-weighted long-run growth rate of earnings for companies in the Standard & Poors 500 index. The second panel shows the level of investment and realized earnings for the same companies. We see that after 1995 the expected annual earnings growth rate rises rapidly, from roughly 11.5 percent to 17.7 in 2001.[1] Investment and earnings forecasts are positively correlated, whereas investment and realized earnings are negatively correlated.[2] One plausible interpretation of these data is that high expectations about earnings growth driven by the prospects of new technologies lead to high levels of investment and to an economic boom. When the new technologies fail to live up to what was expected, investment falls, and a recession ensues.

It is surprisingly difficult to make this story work in a standard business cycle model. Cochrane (1994), Danthine, Donaldson, and Johnsen (1998), and Beaudry and Portier (2004, 2008) find that many variants of the neoclassical growth model fail to generate a boom in response to expectations of higher future total factor productivity (TFP). Good news about future productivity make agents wealthier, so they increase their consumption, as well as their leisure, reducing the labor supply. This fall in labor supply causes output to fall. Therefore, good news about tomorrow generates a recession today!

Our model introduces three elements into the neoclassical growth model that together generate comovement in response to news shocks. These same elements generate comovement in response to contemporaneous shocks. The first element, variable capital utilization, increases the response of output to news about the future. The second element, adjustment costs to investment, gives agents an incentive to respond immediately to news about future fundamentals.[3] The third element, a weak short-run wealth effect on the labor supply, helps generate a rise in hours worked in response to positive news. We introduce this element by using a new class of preferences which gives us the ability to parameterize the strength of the short-run wealth effect on the labor supply. These preferences nest, as special cases, the two classes of utility functions most widely used in the business cycle literature, those characterized in King, Plosser, and Rebelo (1988) and in Greenwood, Hercowitz, and Huffman (1988).

In our quantitative work, we consider a one-sector and a two-sector version of our model. The latter is used to study sectoral comovement. Using our preferences to vary the strength

[1] The realized average annual earnings growth rate is 10 percent for the 1985-95 period and 11 percent for the 1995-2000 period.

[2] The correlation between investment and earnings growth forecasts is 0.48 for the whole sample and 0.72 for the 1995-2004 period. Earnings forecasts lead investment; the correlation between the earnings forecast at time t and investment at time $t+1$ is 0.52 for the full sample. The correlation between investment and realized earnings is -0.40 for the whole sample and -0.57 for the 1995-2004 period.

[3] The first two elements, variable capital utilization and adjustment costs to investment, are generally necessary to generate comovement in response to contemporaneous investment-specific shocks, see Greenwood, Hercowitz, and Krusell (2000).

of short-run wealth effects on the labor supply we find that these effects lie at the heart of the model's ability to generate comovement. We can generate *aggregate* comovement in the presence of moderate labor-supply wealth effects. However, low short-run labor-supply wealth effects are essential to generate *sectoral* comovement that is robust to the timing and nature of the shocks.[4]

Our work is related to several recent papers on the role of news and expectations as drivers of business cycles. Beaudry and Portier (2004) propose the first model that produces an expansion in response to news. Their model features two complementary consumption goods, one durable and one non-durable. Both goods are produced with labor and a fixed factor but with no physical capital. The model generates a boom in response to good news about TFP in the non-durable goods sector. Christiano, Ilut, Motto, and Rostagno (2007) show that habit persistence and investment adjustment costs produce aggregate comovement in response to news about a future TFP shock. In their model, intertemporal substitution in the supply of labor is large enough to compensate for the negative wealth effect of the news shock on the labor supply. However, hours worked fall when the shock materializes because there continues to be a negative wealth effect on labor supply, but there is no longer a strong intertemporal substitution effect on labor supply. Denhaan and Kaltenbrunner (2005) study the effects of news in a matching model. Matching frictions are a form of labor adjustment costs, so their model is related to the version of our model with adjustment costs to labor, which we discuss in section 4. Lorenzoni (2005) studies a model in which productivity has a temporary and a permanent component and agents have imperfect information about the relative importance of these two components. Blanchard (2007) emphasizes the importance of news about future fundamentals in an open economy setting.

Our paper is organized as follows. In Section 2 we propose a one-sector model that generates aggregate comovement with respect to news about TFP and investment-specific shocks. In Section 3 we explore the role that capital utilization, adjustment costs, and preferences play in these results. In Section 4 we present a two-sector model that generates sectoral comovement with respect to both contemporaneous and news shocks to fundamentals. The fundamentals that we consider are aggregate TFP shocks and sectoral TFP shocks to consumption and investment. In Section 5 we study simulations of a version of our one-sector

[4]Imbens, Rubin, and Sacerdote (1999) provide microeconomic evidence that is consistent with the view that short-run wealth effects on the labor supply are weak. Their evidence is based on a sample of lottery prize winners. They find that prizes of $15,000 per year for twenty years have no effect on the labor supply.

model with investment-specific technological progress in which agents receive forecasts about future output growth. Section 6 concludes.

2. The one-sector model

Our model economy is populated by identical agents who maximize their lifetime utility (U) defined over sequences of consumption (C_t) and hours worked (N_t):

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left(C_t - \psi N_t^{\theta} X_t\right)^{1-\sigma} - 1}{1-\sigma}, \tag{2.1}$$

where

$$X_t = C_t^{\gamma} X_{t-1}^{1-\gamma}, \tag{2.2}$$

and E_0 denotes the expectation conditional on the information available at time zero. We assume that $0 < \beta < 1$, $\theta > 1$, $\psi > 0$, and $\sigma > 0$. Agents internalize the dynamics of X_t in their maximization problem. The presence of X_t makes preferences non-time-separable in consumption and hours worked. These preferences nest as special cases the two classes of utility functions most widely used in the business cycle literature. When $\gamma = 1$ we obtain preferences of the class discussed in King, Plosser, and Rebelo (1988), which we refer to as KPR. When $\gamma = 0$ we obtain the preferences proposed by Greenwood, Hercowitz, and Huffman (1988), which we refer to as GHH.

Output (Y_t) is produced with a Cobb-Douglas production function using capital services and labor:

$$Y_t = A_t \left(u_t K_t\right)^{1-\alpha} N_t^{\alpha}. \tag{2.3}$$

Here A_t represents the level of TFP. Capital services are equal to the product of the stock of capital (K_t) and the rate of capital utilization (u_t). Output can be used for consumption or investment (I_t):

$$Y_t = C_t + I_t / z_t. \tag{2.4}$$

The variable z_t represents the current state of technology for producing capital goods. We interpret an increase in z_t as resulting from investment-specific technological progress, as in Greenwood, Hercowitz, and Krusell (2000). Combining (2.3) and (2.4) we obtain:

$$A_t \left(u_t K_t\right)^{1-\alpha} N_t^{\alpha} = C_t + I_t / z_t. \tag{2.5}$$

Capital accumulation is given by:

$$K_{t+1} = I_t \left[1 - \phi\left(\frac{I_t}{I_{t-1}}\right)\right] + [1 - \delta(u_t)]K_t. \tag{2.6}$$

The function $\phi(.)$ represents adjustment costs that are incurred when the level of investment changes over time. We assume that $\phi(1) = 0$, $\phi'(1) = 0$, so that there are no adjustment costs in the steady state, and that $\phi''(1) > 0$. Christiano, Eichenbaum, and Evans (2005) (henceforth CEE) argue that this form of adjustment costs is better at mimicking the response of investment to a monetary shock than the specifications in Lucas and Prescott (1971), Abel and Blanchard (1983), and Hayashi (1982).[5]

The function $\delta(u_t)$ represents the rate of capital depreciation. We assume that depreciation is convex in the rate of utilization: $\delta'(u_t) > 0$, $\delta''(u_t) \geq 0$. The initial conditions of the model are K_0, I_{-1}, and $X_{-1} > 0$.

The first-order conditions for this economy's planning problem are:

$$\left(C_t - \psi N_t^\theta X_t\right)^{-\sigma} + \mu_t \gamma C_t^{\gamma-1} X_{t-1}^{1-\gamma} = \lambda_t, \tag{2.7}$$

$$\left(C_t - \psi N_t^\theta X_t\right)^{-\sigma} \psi N_t^\theta + \mu_t = \beta E_t\left[\mu_{t+1}(1-\gamma) C_{t+1}^{\gamma} X_t^{-\gamma}\right], \tag{2.8}$$

$$\left(C_t - \psi N_t^\theta X_t\right)^{-\sigma} \theta \psi N_t^{\theta-1} X_t = \lambda_t \alpha A_t \left(u_t K_t\right)^{1-\alpha} N_t^{\alpha-1}, \tag{2.9}$$

$$\lambda_t(1-\alpha) A_t u_t^{-\alpha} K_t^{1-\alpha} N_t^\alpha = \eta_t \delta'(u_t) K_t, \tag{2.10}$$

$$\eta_t = \beta E_t[\lambda_{t+1}(1-\alpha) A_{t+1} u_{t+1}^{1-\alpha} K_{t+1}^{-\alpha} N_{t+1}^\alpha + \eta_{t+1}[1 - \delta(u_{t+1})], \tag{2.11}$$

$$\lambda_t / z_t = \eta_t \left[1 - \phi\left(\frac{I_t}{I_{t-1}}\right) - \phi'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + E_t\left[\beta \eta_{t+1} \phi'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right], \tag{2.12}$$

where μ_t, λ_t, and η_t are the Lagrange multipliers associated with (2.2), (2.5), and (2.6), respectively.

We choose the following parameter values for our benchmark model. We set $\sigma = 1$, which corresponds to the case of logarithmic utility. We set θ to 1.4, which corresponds to an elasticity of labor supply of 2.5 when preferences take the GHH form. We set the discount factor β to 0.985, implying a quarterly steady-state real interest rate of 1.5 percent. The share of labor in the production function, α, is set to 0.64. We set the value of γ to 0.001, so preferences are close to a GHH specification. We choose the second derivative of

[5] Lucca (2007) provides microfoundations for the CEE adjustment cost formulation. He shows that these adjustments costs are equivalent, up to a first-order approximation, to a model in which there is time to build and where firms invest in many complementary projects that have uncertain duration.

the adjustment-cost functions evaluated at the steady state, $\phi''(1)$, to equal 1.3. Finally, we set the elasticity of $\delta'(u)$ evaluated in the steady state ($\delta''(u)u/\delta'(u)$, where u is the level of utilization in the steady state) to 0.15. The value of $\delta''(u)u/\delta'(u)$ influences the degree of shock amplification present in the economy. When $\delta''(u)u/\delta'(u)$ is low, the cost of utilization rises slowly with the level of utilization. In this case, the level of capital utilization is highly responsive to shocks, resulting in a powerful amplification mechanism. Since there is little guidance in the literature about appropriate values for $\phi''(1)$ and $\delta''(u)$, we discuss below the robustness of our results to these parameters. We solve the model by linearizing the equations that characterize the planner's problem around the steady state.

News shocks Given these parameter values, the model produces aggregate comovement in response to both contemporaneous shocks to A_t or z_t and to news about future values of A_t or z_t. Most macroeconomic models generate aggregate comovement in response to contemporaneous shocks. For this reason, we focus our discussion on the response of our model to news shocks.

The timing of the news shock we consider is as follows. At time zero the economy is in the steady state. At time one, unanticipated news arrives. Agents learn that there will be a one-percent permanent increase in A_t or z_t beginning two periods later, in period three. Figure 2 depicts the response of the economy to this news. In all cases, there is an expansion in periods one and two in response to positive news about future productivity. Consumption, investment, output, hours worked, average labor productivity, and capital utilization all rise in periods one and two even though the positive shock only occurs in period three.[6]

Figure 2 shows that the impact of news about A_t is less important than the realization of the A_t shock. An increase in A_t, once it materializes, has an immediate, direct impact on output. On the other hand, news of a future increase in A_t affects output only through changes in the supply of labor and in the amount of capital that is accumulated before the shock arrives.

In contrast, with investment-specific technical change, most of the rise in output occurs in period one, when the news arrives, not in period three, when the z_t shock materializes. This property results from the fact that an increase in z_t does not have a direct effect on

[6] Beaudry and Portier (2008) provide a useful characterization of the class of models that cannot generate aggregate comovement in response to news about future TFP. Our model has preferences and investment adjustment costs that are outside the set of specifications that they consider.

output. Output is only affected by changes in the supply of labor and in the amount of capital accumulated both before and after the realization of the shock.

Table 1 shows that there is a wide range of parameters that generate aggregate comovement in response to news about future A_t and z_t. This table is constructed by using our benchmark calibration and changing one parameter at a time to find the range of values for this parameter consistent with aggregate comovement in the period in which the news arrives. We find that adjustments to investment do not have to be high, ($\phi''(1) > 0.4$), varying utilization can be relatively costly ($\delta''(u)u/\delta'(u) < 2.5$), and the labor supply does not need to be very responsive ($\theta < 10$). The value of γ has to be lower than 0.4. Therefore, although the model does not generate aggregate comovement when preferences take the KPR form, short-run wealth effects on the labor supply can still be substantial.

3. The elements of the one-sector model

In this section we discuss the role played by the three features of the model that generate comovement between consumption, investment, output, and hours worked in response to news about the future values of A_t or z_t. In discussing the influence of capital utilization and adjustment costs on investment decisions it is useful to consider a version of the model with GHH preferences ($\gamma = 0$). In this case X_t is constant so, to simplify, we normalize the level of X to one. The first-order conditions for the planner's problem for this version of the model are:

$$\left(C_t - \psi N_t^{\theta}\right)^{-\sigma} = \lambda_t, \tag{3.1}$$

$$\theta \psi N_t^{\theta-1} = \alpha A_t \left(u_t K_t\right)^{1-\alpha} N_t^{\alpha-1}, \tag{3.2}$$

together with (2.10), (2.11), and (2.12).

Variable Capital Utilization To explain the role played by capital utilization, we consider a version of the model with constant capital utilization. To obtain the planner's first-order conditions for this model, we eliminate the first-order condition for u_t, (2.10), set $u_t = 1$ in equations (2.5) and (3.2), and $\delta(u_t) = \delta$ in equation (2.6):

$$\theta \psi N_t^{\theta-1} = \alpha A_t K_t^{1-\alpha} N_t^{\alpha-1}. \tag{3.3}$$

This equation implies that N_t does not respond to news about future changes in A_t or z_t. The positive wealth effect of future shocks reduces the marginal utility of consumption today, λ_t.

Equation (3.1) implies that C_t rises. When $u_t = 1$, equation (2.5) implies that investment must fall. Therefore, labor and output do not respond to the news shock, consumption rises, and investment falls. In the case of variable utilization, equation (3.2) implies that an increase in utilization raises the marginal product of labor. This increase provides an incentive for hours worked to rise.

Preferences To understand the role of preferences in shaping the effects of news about the future it is useful to study the problem of a worker in our economy.

We first consider the response of a worker to a contemporaneous, permanent increase in the real wage, w_t. To simplify, we abstract from uncertainty and assume that the real interest rate is constant and given by: $r = 1/\beta - 1$. The worker's problem is to maximize (2.1) subject to the budget constraint:

$$a_{t+1} = (1 + r)a_t + w_t N_t - C_t,$$

and to the non-Ponzi game condition, $\lim_{t\to\infty} a_{t+1}/(1 + r)^t = 0$, and the initial value of the worker's assets, a_0. The timing is as follows. At time zero, the worker is in the steady state with a constant wage rate. At time one, there is an unanticipated, one percent permanent increase in w_t. The first panel of Figure 3 shows the response of N_t for four different values of γ: zero, 0.001, 0.25, and one. The strongest response of N_t occurs with GHH preferences ($\gamma = 0$). However, in this case hours worked are not stationary, they rise permanently.[7] With KPR preferences ($\gamma = 1$), N_t converges back to the steady state after the shock, but its short-run response is very weak. When γ is equal to 0.001 or 0.25, the short-run impact of the wage rise on N_t is in between that obtained with GHH and KPR preferences. Lower values of γ produce short-run responses that are closer to those obtained with GHH preferences. As long as $0 < \gamma \leq 1$, hours worked converge to the steady state.

We now compute the Hicksian wealth effect on hours worked of the real wage increase. We denote by U and U^* the lifetime utility of the worker before and after the permanent increase in w_t, respectively. To calculate the wealth effect we compute the path of N_t for a worker who does not benefit from the wage increase but who receives an output transfer at

[7] A simple way to make hours stationary when preferences take a GHH form is to introduce a trend in the utility function such that the utility cost of supplying labor increases at the same rate as the real wage. This trend can be justified by appealing to home production. However, we find that, in models with stochastic technical progress, this formulation can generate large recessions through an implausible mechanism. In periods with low rates of technical progress, hours worked can fall significantly because the trend increase in the utility cost of supplying labor is not offset by increases in the real wage rate.

time one that raises his utility to U^*. This wealth effect is zero for GHH preferences and negative for KPR. In both cases the wealth effect is constant over time. When $0 < \gamma < 1$ the wealth effect varies over time. In the long run, this effect is similar to that with KPR preferences. In the short-run, the effect is actually positive, helping to raise the labor supply. This positive wealth effect results from the fact that the disutility of work is high when X_t is high.[8] Since consumption rises over time, X_t also increases over time, and the disutility of work is higher in the future than in the present.

It is easy to see why it is generally difficult to generate an expansion in response to good news about the future with KPR preferences. Suppose we tell a worker with KPR preferences that his real wage goes up in the future but not in the present. This news generates a wealth effect that reduces the worker's supply of labor today.

Investment Adjustment Costs The first-order condition for labor, (3.2), implies that, unless the rate of capital utilization changes, N_t does not respond to news about the future. The first-order condition for capital utilization, (2.10), implies that η_t/λ_t must fall in order for u_t to rise. A fall in η_t/λ_t requires the presence of adjustment costs to investment. Without adjustment costs, $\eta_t/\lambda_t = z_t$ and the capital utilization equation reduces to:

$$(1-\alpha)A_t u_t^{-\alpha} K_t^{1-\alpha} N_t^{\alpha} = z_t \delta'(u_t) K_t.$$

Since z_t and A_t both remain constant at time two, this equation along with (3.2) implies that both N_t and u_t remain constant.

We can now put all the elements of the model together to explain how we can generate comovement in response to news about the future. A future increase in A_t or z_t implies that investment will rise in the future. In the presence of investment adjustment costs it is optimal to smooth investment over time, and so investment rises in period one. An increase in investment leads to a decline in η_t/λ_t, the value of installed capital in units of consumption. This fall occurs because the adjustment costs embedded in (2.6) imply that higher levels of investment today reduce the cost of investment tomorrow.

The fall in η_t/λ_t lowers the value of installed capital. Capital is less valuable because it is less costly to replace, so it is efficient to increase today's rate of capital utilization. The rise in utilization increases the marginal product of labor. This increase provides an incentive

[8] The disutility of labor at time t is given by: $\left(C_t - \psi N_t^{\theta} X_t\right)^{-\sigma} \theta \psi N_t^{\theta-1} X_t$. It is easy to see that this disutility is increasing in X_t.

for hours worked to rise. As long as the wealth effect on the supply of labor is small enough, hours rise and we see an expansion in response to good news about future values of A_t or z_t.

Implications for the Value of the Firm The ratio η_t/λ_t is equal to Tobin's marginal q, which is the value of an additional unit of installed capital. Therefore, to generate comovement, good news about future productivity must lead to a fall in Tobin's marginal q. A natural question is: does this fall imply a decline in the value of firm? The answer is no because with CEE adjustment costs, average q (the ratio of firm value to the capital stock) is different from marginal q. To see this result, define the end-of period value of the firm as the result of the following problem:[9]

$$V(K_1, I_0, A_0, z_0) = \max E_0 \sum_{t=1}^{\infty} \frac{\beta^t \lambda_t}{\lambda_0} \left[A_t \left(u_t K_t\right)^{1-\alpha} N_t^{\alpha} - w_t N_t - I_t/z_t\right],$$

subject to (2.6). The expression $V(K_1, I_0, A_0, z_0)$ represents the time-zero value of the firm after it receives the cash flow $(Y_0 - w_0 N_0)$, incurs investment expenses (I_0/z_0), and chooses values for I_1 and K_1. We show in the Appendix that $V(K_1, I_0, z_0)$ can be written as:

$$V(K_1, I_0, A_0, z_0) = \frac{\eta_0}{\lambda_0}\left(1-\delta\right) K_0 + I_0 \left\{1/z_0 + \frac{\eta_0}{\lambda_0}\left[\phi'\left(\frac{I_0}{I_{-1}}\right)\left(\frac{I_0}{I_{-1}}\right)\right]\right\}. \qquad (3.4)$$

The value of the firm is the sum of two components. The first component, $(\eta_0/\lambda_0)(1-\delta) K_0$, is the value of the capital stock. The second component, is the value of investment. This second term is present because higher investment today lowers the cost of higher investment in the future.

News about future A_t or z_t reduce the value of the capital stock but can raise the value of investment. For our parameter values, the value of the capital falls and the value of the investment rises. The first effect dominates so the overall value of the firm falls.

An easy way to overturn this implication without changing any of the other key properties of our model is to introduce decreasing returns to scale into the production function. We find that the value of the firm rises in response to news about future increases in A_t or z_t when the degree of returns to scale is lower than 0.9. A production function that exhibits decreasing returns to capital and labor can be written as: $Y_t = A_t \left(u_t K_t\right)^{\alpha_1} N_t^{\alpha_2} T^{1-\alpha_2-\alpha_3}$, where $\alpha_1 + \alpha_2 < 1$, and T can be interpreted as a production factor that belongs to the

[9] Our motivation for using the end-of-period value of the firm is as follows. In a discrete-time version of the Hayashi (1982) model marginal and average q coincide only when they are based on the end-of-period value of the firm. This timing is not required in continuous time, see the Appendix.

firm.[10] The value of this factor increases whenever there is an increase in the future values of A_t or z_t.[11] This effect produces an overall increase in the value of the firm.

4. The two-sector model

To study sectoral comovement we consider a two-sector version of our model with a consumption sector and an investment sector.[12] Preferences are described by (2.1) and (2.2). The resource constraint (2.5) is replaced with the following two equations:

$$C_t = A_t z_t^c \left(u_t^c K_t^c\right)^{1-\alpha} \left(N_t^c\right)^{\alpha}, \tag{4.1}$$

$$I_t^c + I_t^i = A_t z_t^i \left(u_t^i K_t^i\right)^{1-\alpha} \left(N_t^i\right)^{\alpha}, \tag{4.2}$$

where the superscript c and i denotes variables that are specific to the consumption and investment sector, respectively. The capital accumulation equation, (2.6), is replaced by:

$$K_{t+1}^c = I_t^c \left[1 - \phi\left(\frac{I_t^c}{I_{t-1}^c}\right)\right] + [1 - \delta(u_t^c)] K_t^c, \tag{4.3}$$

$$K_{t+1}^i = I_t^i \left[1 - \phi\left(\frac{I_t^i}{I_{t-1}^i}\right)\right] + [1 - \delta(u_t^i)] K_t^i. \tag{4.4}$$

Finally, we introduce the condition:

$$N_t^c + N_t^i = N_t.$$

Before turning to our results it is useful to review Christiano and Fitzgerald's (1998) discussion of why sectoral comovement of hours worked cannot arise with KPR preferences. Combining the first-order conditions for consumption and labor for the case of $\gamma = 1$ yields the following expression:

$$\theta\psi \left(N_t^c + N_t^i\right)^{\theta-1} = \alpha / N_t^c. \tag{4.5}$$

[10] A degree of returns to scale of 0.9 is consistent with the estimates in Burnside (1996). The factor T can be interpreted as organizational capital, see Prescott and Visscher (1980).

[11] Another avenue to generate an increase in the value of the firm in response to news shocks is to introduce adjustment costs to labor (see the Appendix). These adjustment costs add a term similar to the investment value to the overall value of the firm.

[12] See Huffman and Wynne (1998) for evidence on sectoral comovement. These authors propose a model that generates sectoral comovement in response to contemporaneous shocks. Their model does not produce comovement in response to news shocks because it has no forces that can compensate for the negative wealth effect on the labor supply of news about future fundamentals.

Equation (4.5) implies that N_t^c and N_t^i cannot move in the same direction. The analogous equation for the case of GHH preferences is:

$$\theta\psi\left(N_t^c + N_t^i\right)^{\theta-1} = \alpha\frac{C_t}{N_t^c}. \tag{4.6}$$

Equation (4.6) shows that with GHH preferences it is possible for N_t^c and N_t^i to move in the same direction. The fact that comovement is not possible with $\gamma = 1$ but it is possible with $\gamma = 0$ suggests that wealth effects on the labor supply plays a crucial role in determining sectoral comovement.[13] Our preferences allow us to consider intermediate values of γ to obtain a better understanding of the role played by short-run wealth effects on the labor supply in generating sectoral comovement.

We now discuss numerical results for a version of the model calibrated with the same parameter values used for the one-sector model. Figure 4 shows the effects of three different permanent, contemporaneous one-percent shocks. The first shock is an aggregate TFP shock (A_t). The second is a sectoral shock to TFP in the consumption sector (z_t^c). The third is a sectoral shock to TFP in the investment sector (z_t^i or, equivalently, z_t). The timing is as follows. The economy is in the steady state at time zero and the shock occurs at time one. It is clear from Figure 4 that the model generates both aggregate and sectoral comovement in response to all three shocks.

Figure 5 shows the response to news about the same three shocks $\left(A_t,\ z_t^c,\ \text{and}\ z_t^i\right)$. The timing is as follows. The economy is in the steady state at time zero. At time one the economy learns that there is a permanent, one-percent increase in one of the three shocks in period three. Figure 5 shows that the model generates both aggregate and sectoral comovement in response to news about all three shocks.

Robustness To understand better the mechanism that drives the results displayed in Figures 4 and 5 we now discuss the range of parameters that generate sectoral comovement with respect to contemporaneous and news shocks. We follow the same procedure we use to study robustness in the one-sector model.

Table 1 shows that it is easy to generate comovement with respect to contemporaneous shocks to z_t^c, even with KPR preferences. Generating sectoral comovement in response

[13] The results in DiCecio (2005) also suggest that wealth effects play a central role in generating sectoral comovement in response to contemporaneous shocks. In his model there is sectoral comovement because wages are sticky. Workers have to supply the number of hours demanded by firms at a fixed nominal wage, and so the wealth effect on the labor supply plays no role in the short run.

to contemporaneous shocks to A_t requires only that short-run wealth effects be somewhat weaker than those implied by KPR ($\gamma < 0.6$). In both of these cases minimal adjustment costs to investment are required and variable utilization is not necessary. It is much more difficult to generate sectoral comovement in response to contemporaneous shocks to z_t^i. We need very weak short-run wealth effects ($\gamma < 0.11$) and a responsive labor supply ($\theta < 2$). We also need variable utilization, but increasing utilization can be relatively costly ($\delta''(u)u/\delta'(u) < 2.8$).

Finally, it is essential to have low values of γ ($\gamma < 0.006$) to obtain sectoral comovement in response to news about A_t, z_t^c, and z_t^i. We also need moderate investment adjustment costs ($\phi''(1) > 1$), a low elasticity of the cost of utilization with respect to the rate of utilization ($\delta''(u)u/\delta'(u) < 0.25$), and a responsive labor supply ($\theta < 1.6$).

We find that sectoral comovement of labor and of investment are driven by different features of the model. Low values of γ are essential to generate comovement of labor in the two sectors. Investment adjustment costs are important to generate comovement in sectoral investment.

Adjustment Costs to Labor We now consider a version of our model that incorporates adjustment costs to labor, along the lines of Sargent (1978) and Cogley and Nason (1995). We replace equations (4.1) and (4.2) with the following two equations:

$$C_t + N_t^c \varphi(N_t^c / N_{t-1}^c) = A_t z_t^c \left(u_t^c K_t^c\right)^{1-\alpha} \left(N_t^c\right)^{\alpha},$$

$$I_t^c + I_t^i + N_t^i \varphi(N_t^i / N_{t-1}^i) = A_t z_t^i \left(u_t^i K_t^i\right)^{1-\alpha} \left(N_t^i\right)^{\alpha},$$

where $\varphi(.)$ is a function such that $\varphi(1) = \varphi'(1) = 0$, $\varphi'(.) \geq 0$, and $\varphi''(.) > 0$.

We find that adjustment costs to labor help generate aggregate comovement with respect to news shocks. These costs provide an incentive to increase the labor supply immediately in anticipation of future increases in the labor supply that occur in response to the shock. In the presence of adjustment costs it is not efficient to reduce the labor supply today and then increase it in the future once the shock occurs. As a result, the short-run wealth effect on the labor supply can be stronger than in the benchmark model. Indeed, we find that the introduction of labor adjustment costs allows the model to generate aggregate comovement in the one-sector model in response to news about A_t or z_t for a much wider range of parameters, including high values of γ. However, we find that adjustment costs to labor do not help with generating sectoral comovement in response to news shocks in the two-sector model.

5. Model Simulations

We have shown that our model can generate expansions and contractions in response to good news about future productivity. One natural question is whether this success comes at a cost of the model's ability to generate empirically recognizable business fluctuations. That is, can the model, when calibrated with the same parameters used in the experiments discussed so far, generate volatility, comovement, and persistence of macroeconomic aggregates that are empirically plausible? To answer this question we simulate a version of our model driven by stochastic, investment-specific technical progress and compute the standard set of business-cycle statistics.[14] We assume that $\log(z_t)$ follows a random walk:

$$\log(z_{t+1}) = \log(z_t) + \varepsilon_{t+1}.$$

We use the method proposed by Tauchen and Hussey (1991) to estimate a two-point Markov chain for ε_t. We measure z_t using quarterly data on the U.S. real price of investment for the period 1947.I to 2004.IV. These data were constructed by Fisher (2006) using National Income and Product Accounts series for the consumption deflator and Cummins and Violante's (2002) updated series for Gordon's (1989) quality-adjusted producer durable-equipment deflator.[15] The support of the estimated Markov chain is: $\{0.00, 0.0115\}$. The transition matrix is:

$$\pi = \begin{bmatrix} 0.7378 & 0.2622 \\ 0.2622 & 0.7378 \end{bmatrix}. \tag{5.1}$$

We generate 1000 model simulations with 230 periods each. For each simulation, we detrend the logarithm of the relevant time series with the Hodrick-Prescott filter using a smoothing parameter of 1600. In our main calibration we consider a setting in which agents receive noisy news about the future. Our measure of news is based on the Livingston survey of output forecasts.[16] The Livingston survey pools professional forecasters to obtain forecasts of different economic variables. Two-quarter ahead GDP forecasts are available for the period

[14] Fisher (2006) and Justiniano and Primiceri (2005) argue that investment-specific technical progress is the most important determinant of output variability.

[15] We thank Ricardo DiCecio for providing us with an updated version of this time series.

[16] See Croushore (1993) for a description of the Livingston survey. The Survey of Professional Forecasters (SPF) is an alternative source of output growth forecasts for the U.S. economy. We also use SPF forecasts to calibrate our model. The results are similar to those we obtain with the Livingston forecasts.

1971.IV – 2003.IV. To study the robustness of the results to different assumptions about the timing of information arrival, we simulate the model under two additional information scenarios. In the first scenario agents receive no news. In the second scenario agents receive perfect information about z_t^i.

Noisy News Forecasts of future rates of investment-specific technical change are not available for our sample, so it is difficult to choose the precision of signals about ε_{t+2}. For this reason, we consider a setting in which we provide agents with a signal, S^y, for whether the growth rate of output two periods later is going to be above or below the average. The signal has two values, high (H) or low (L). We choose the signal to have the same precision as the Livingston survey of output forecasts. To obtain a discrete signal with two possible values we use the Tauchen and Hussey (1991) method to estimate a two-point Markov chain for the Livingston survey forecasts. The precision of these forecasts is as follows:

$$\begin{aligned} \Pr(g_{t+2}^y &\geq \text{Average}(g^y)|S^y = H) = 0.70, \\ \Pr(g_{t+2}^y &< \text{Average}(g^y)|S^l = L) = 0.58, \end{aligned} \tag{5.2}$$

where g_{t+2}^y represents the growth rate of output at time $t+2$. The forecast precision is higher in expansions than in recessions.[17]

To provide agents in the model with a signal on output with the same precision as the Livingston survey forecast, we implement the following algorithm. First, we assume values q_1 and q_2 for the following conditional probabilities:

$$\begin{aligned} \Pr(S^y &= H|\varepsilon_{t+2} = H) = q_1, \\ \Pr(S^y &= L|\varepsilon_{t+2} = L) = q_2. \end{aligned}$$

We simulate time series for ε_t and generate S^y according to q_1 and q_2. Agents receive these signals and forecast ε_{t+2} using both the signal and the current realization of ε_t:

$$\Pr(\varepsilon_{t+2} = H|S^y = i, \varepsilon_t) = \frac{\Pr(S^y = i|\varepsilon_{t+2} = H)\Pr(\varepsilon_{t+2} = H|\varepsilon_t)}{\sum_{j=H,L}\Pr(S^y = i|\varepsilon_{t+2} = j)\Pr(\varepsilon_{t+2} = j|\varepsilon_t)}.$$

[17]Using the Survey of Professional Forecasters, Van Nieuwerburgh and Veldkamp (2006) also find that forecast precision is higher in expansions than in recessions.

We simulate the model and compute:

$$\Pr(g_{t+2}^{y} \geq \text{Average}(g^{y})|S^{y}=H),$$
$$\Pr(g_{t+2}^{y} < \text{Average}(g^{y})|S^{l}=L).$$

We then revise the values of q_1 and q_2 until the precision of S^y in the model coincides with the precision (5.2) estimated in the data. We obtain $q_1 = 0.99$ and $q_2 = 0.62$.

Column 5 of Table 2 shows the results for this version of the model. This model generates business cycle moments that are similar to those in postwar U.S. data reported in column 1. Consumption, investment, and hours worked are procyclical. Investment is more volatile than output, consumption is less volatile than output, and the volatility of hours is similar to that of output. The model accounts for 64 percent of the standard deviation of output in the data.

Robustness To understand the robustness of our results to different assumptions about the timing of information arrival we consider two additional cases. In the first case agents receive no news about the future. In the second case agents receive a perfect signal about ε_{t+2}.

Table 2 reports moments for U.S. data and model simulated data. These moments were computed using data detrended with the HP filter with a smoothing parameter of 1600. Column 4 in Table 2 summarizes the business cycle properties of a version of our model in which the economy receives no news. Forecasts of future values of ε_t are solely based on the Markov chain (5.1). This version of the model generates business cycle moments that are similar to those in the postwar U.S. data we report in column 1. Consumption, investment, and hours worked are procyclical. Investment is more volatile than output, consumption is less volatile than output, and the volatility of hours is similar to that of output. Column 6 of Table 2 summarizes the business cycle properties of our model when at time t agents receive perfect signals about ε_{t+2}, the growth rate of z_t in two periods. This model generates patterns of volatility and comovement that are similar to those of the model with no news.

To summarize, Columns 4 and 6 show that the business cycle implications of our model are robust to changes in the information structure of the shocks. Providing the economy with news about the future does not alter the basic patterns of comovement or relative volatility of the major macroeconomic aggregates. Therefore the business cycle properties of our model are robust to the timing of information arrival. In contrast, the business cycle properties of the neoclassical one-sector growth model depend heavily on the timing of information arrival.

News and Volatility It is well known that in the past 60 years output volatility has declined and output persistence has increased in virtually all developed countries. These facts are documented for the U.S. in Table 2. Columns 2 and 3 provide statistics for the U.S. for the period 1947-1982 and 1983-2003. The volatility of output declines from 1.88 in the first sample to 0.97 in the second sample. The persistence of output, as measured by the sum of the four estimated coefficients in an AR(4) process for output, rises from 0.65 to 0.86.

Stock and Watson (2003) document both the reduction in output volatility and the increase in persistence for the G7 countries and discuss several possible explanations, including better monetary policy, changes in sectoral composition toward sectors with lower volatility, and declines in the volatility of the shocks to the economy.

Our model provides a complementary explanation for the volatility decline and persistence increase. Advances in information technology have led to dramatic increases in the volume of available data and in the ability to process these data. Let us assume that the increase in information volume has made it easier to forecast the future. Under this assumption, we can think of the increased volume of information as moving the economy from Column 4 of Table 2 (no news) toward Column 6. An increase in the availability of news makes it easier to forecast the future, thus reducing economic volatility and increasing persistence.

Evidence from the Livingston survey is consistent with the idea that business cycles have become easier to forecast. The survey contains unemployment forecasts at a six-month horizon from the fourth quarter of 1961 to the fourth quarter of 2003. The average absolute percentage forecast error is 3.3 percent in the first part of the sample (1961.IV-1982.IV) but only 1.5 percent in the second part of the sample (1983.I-2003.IV). Therefore, the forecast error declined by 79 percent. This increase in forecast precision cannot be solely accounted for by the reduction in unemployment volatility. The standard deviation of log(unemployment) declined only by 23 percent between the first and the second part of the sample.

Recessions According to our estimated Markov chain, (5.1), the rate of technical progress is always positive. This Markov process is a good approximation to the behavior of investment-specific technical progress in the data. Declines in z_t are rare (they occur in only 6 percent of the quarters in our sample) and small in magnitude. The average percentage decline in z_t in quarters in which z_t falls is 0.8 percent.

The absence of technical regress in our calibration raises the question of whether the model can generate recessions.[18] To study this question we first describe a simple method to determine the timing of recessions. Our strategy is similar to that used by the Business Cycle Dating Committee of the National Bureau of Economic Research (NBER) for comparing different recessions (see Hall, Feldstein, Frankel, Gordon, Romer, Romer, and Zarnowitz (2003)). It is also reminiscent of the methods used by Burns and Mitchell (1946) in their study of the properties of U.S. business cycles.

To date the beginning of U.S. recessions, we compute trend output using the HP filter with a smoothing parameter of 1600. We identify periods in which output is below trend for at least two consecutive quarters, say t and $t+1$. Recessions are dated as starting at time $t-1$. This timing method produces recession dates that are similar to those chosen by the NBER dating committee.[19]

We compute the average time series for different macroeconomic variables during recession periods for the U.S. economy. The solid line in Figure 6 shows the average behavior during recessions of the HP-detrended logarithm of real GDP, real consumption of nondurables and services, real private investment, and hours worked. Time zero is the quarter in which the recession begins. The dashed lines represent the 95 percent confidence interval around the average for each variable. The fall from peak to trough in output, consumption, investment, and hours is 1.8 percent, 0.7 percent, 4.3 percent, and 1.7 percent, respectively.

The dashed line in Figure 6 shows the average recession in our model. The model captures the salient features of recessions in the data. The last graph in this figure, which displays the behavior of investment-specific technical change in the average recession, shows an interesting feature of the recessions generated by the model. On average, recessions occur when there

[18] King and Rebelo (1999) propose a real business cycle model that generates recessions in the absence of negative technology shocks. Their model shares one key feature with our model, which is variable capital utilization, but it relies on a much higher elasticity of labor supply.

[19] The HP procedure produces six recessions whose starting dates coincide with those chosen by the NBER: 1948.IV, 1957.III, 1960.II, 1980.I, 1981.III, 1990.III. There are four other recessions in which the HP procedure produces recession dates that are within two quarters of the NBER dates (indicated in parentheses): 1953.III (1953.II), 1969.III (1969.IV), 1974.II (1974.III), and 2001.II (2001.I). The HP procedure identifies four additional recessions starting in 1962.II, 1967.II, 1986.III, and 1994.III. None of the latter episodes involves a fall in output, which suggests that our procedure corresponds to a broader definition of recession than that of the NBER.

is a high contemporaneous rate of change in investment-specific technical progress but the economy learns that two periods later technical change will slow down. It is impossible to identify what causes recessions in our model by lining up the usual suspects–contemporaneous shocks to the economy. Recessions are driven not by bad shocks today but by lackluster news about the future. This property is generally not present in a version of the model in which agents do not receive news about the future. In the no-news version of the model recessions tend to coincide with periods in which the rate of investment-specific technical change is low.

The model only generates nine recessions, as opposed to 14 in the data. In addition, recessions are more shallow in the model that in the data. These two differences between the implications of the model and U.S. data occur in part because the U.S. economy is affected by shocks, such as oil shocks, that are absent from the model.

6. Conclusion

Aggregate and sectoral comovement are central features of business cycles data. Therefore, the ability to generate comovement is a natural litmus test for macroeconomic models. But it is a test that most existing models fail. In this paper we propose a unified model that generates both aggregate and sectoral comovement in response to both contemporaneous shocks and news shocks about fundamentals. The fundamentals that we consider are aggregate TFP shocks, TFP shocks to the consumption and investment sector, and shocks to investment-specific technical change. The model has three key elements: variable capital utilization, adjustment costs to investment, and a new form of preferences that allows us to parameterize the strength of short-run wealth effects on labor supply. We find that, in order for comovement to be robust to the timing and nature of the shocks that buffet the economy, short-run wealth effects on the labor supply must be weak.

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7. Appendix: Adjustment costs and the value of the firm

(not for publication)

In this appendix we discuss the relation between the value of the firm and Tobin's marginal q, which is the value of an additional unit of installed capital. We first discuss results in continuous time and then in discrete time. In both cases, we start by reviewing the classic Hayashi (1982) result that marginal and average q coincide. We then show that this result does not hold when adjustment costs take the form proposed by CEE or in the presence of labor adjustment costs. We characterize the relation between marginal and average q in these settings.

7.1. Continuous time results

7.1.1. Hayashi adjustment costs

To simplify we abstract from uncertainty. The firm's objective is to maximize its value, measured in units of consumption at time zero:[20]

$$\max V_0 = \frac{1}{\lambda_0} \int_0^{\infty} \lambda_t \left[F(K_t, N_t) - w_t N_t - I_t / z_t \right] e^{-rt} dt, \tag{7.1}$$

$$\dot{K}_t = \phi(I_t/K_t) K_t - \delta K_t, \tag{7.2}$$

where the concave function $\phi(.)$ represents adjustment costs to investment and λ_t represents the marginal utility of consumption. The function $F(.)$ is homogeneous of degree one. Written in our notation the key result in Hayashi (1982) is that:

$$V_0 = \frac{\eta_0}{\lambda_0} K_0, \tag{7.3}$$

where η_t is the Lagrange multiplier associated with (7.2). The ratio η_0/λ_0 represents the value of an additional unit of installed capital at time zero. This equation implies that average q, V_0/K_0, is equal to marginal q, η_0/λ_0. This property implies that the dynamics of firm value can be studied by simply characterizing the dynamics of η_t/λ_t. Without this result computing the value of the firm requires evaluating the infinite sum in equation (7.1). The key properties required for average and marginal q to coincide is that both the production

[20] We introduce adjustment costs in the capital accumulation equation to increase the similarity between the Hayashi model and the CEE model. The results that we describe continue to hold when the adjustment costs are introduced as a cost to the firm.

function and the adjustment cost function be homogeneous of degree one. Equation (7.3) can be rewritten as:

$$V_0 = \frac{K_0}{z_0 \phi'(I_0/K_0)}.$$

7.1.2. CEE adjustment costs

The firm's problem when adjustment costs take the form proposed by CEE is:

$$\max V_0 = \frac{1}{\lambda_0} \int_0^\infty \lambda_t \left[F(K_t, N_t) - w_t N_t - I_t/z_t \right] e^{-rt} dt,$$

$$\dot{K}_t = \left[1 - \phi(x_t/I_t) \right] I_t - \delta K_t, \tag{7.4}$$

$$\dot{I}_t = x_t, \tag{7.5}$$

where $\phi(0) = \phi'(0) = 1$, $\phi''(0) > 0$, and $F(.)$ is homogeneous of degree one. Here both K_0 and I_0 are given, so investment is predetermined. The question we are interested in is: does marginal q coincide with average q? The following proposition states that the answer is no.

Proposition 7.1. *The value of the firm is given by:*

$$V_0 = \frac{\eta_0}{\lambda_0} K_0 + \frac{\omega_0}{\lambda_0} I_0,$$

where η_t and ω_t are the Lagrange multipliers associated with (7.4) and (7.5), respectively.

Proof: The Hamiltonian for the firm's problem is:

$$H = \lambda_t \left[F(K_t, N_t) - w_t N_t - I_t/z_t \right] + \eta_t \left\{ \left[1 - \phi(x_t/I_t) \right] I_t - \delta K_t \right\} + \omega_t x_t.$$

The first-order conditions are:

$$\dot{\eta}_t = \eta_t (r + \delta) - \lambda_t F_1(K_t, N_t), \tag{7.6}$$

$$\dot{\omega}_t = r\omega_t + \lambda_t/z_t - \eta_t \left[1 - \phi(x_t/I_t) \right] - \eta_t \phi'(x_t/I_t) \left(x_t/I_t \right), \tag{7.7}$$

$$\omega_t = \eta_t \phi'(x_t/I_t), \tag{7.8}$$

$$w_t = F_2(K_t, N_t). \tag{7.9}$$

The two transversality conditions are:

$$\lim_{t \to \infty} \eta_t K_t e^{-rt} = 0,$$

$$\lim_{t \to \infty} \omega_t I_t e^{-rt} = 0.$$

It is useful to note that:

$$\frac{d}{dt}\left[\eta_t K_t e^{-rt}\right] = \left[\dot{\eta}_t K_t + \eta_t \dot{K}_t - r\eta_t K_t\right] e^{-rt}, \tag{7.10}$$

and that:

$$\int_0^\infty \frac{d}{ds}\left[\eta_s K_s e^{-rs}\right] dt = -\eta_0 K_0. \tag{7.11}$$

Using the law of motion for capital and equation (7.6) we have:

$$\left[\dot{\eta}_t K_t + \eta_t \dot{K}_t - r\eta_t K_t\right] = \left[\eta_t (r+\delta) - \lambda_t F_1(K_t, N_t)\right] K_t + \eta_t \left\{\left[1 - \phi(x_t/I_t)\right] I_t - \delta K_t\right\} - r\eta_t K_t.$$

Simplifying we obtain:

$$\left[\dot{\eta}_t K_t + \eta_t \dot{K}_t - r\eta_t K_t\right] = -\lambda_t F_1(K_t, N_t) K_t + \eta_t \left[1 - \phi(x_t/I_t)\right] I_t. \tag{7.12}$$

Using (7.10), (7.11), and (7.12) we have:

$$-\eta_0 K_0 = \int_0^\infty \left\{-\lambda_t F_1(K_t, N_t) K_t + \eta_t \left[1 - \phi(x_t/I_t)\right] I_t\right\} e^{-rt} dt.$$

Since $F(.)$ is homogeneous of degree one in K_t and N_t:

$$F_1(K_t, N_t) K_t = F(K_t, N_t) - F_2(K_t, N_t) N_t.$$

Using this fact:

$$-\eta_0 K_0 = \int_0^\infty \left\{-\lambda_t \left[F(K_t, N_t) - F_2(K_t, N_t) N_t\right] + \eta_t \left[1 - \phi(x_t/I_t)\right] I_t\right\} e^{-rt} dt. \tag{7.13}$$

Using equation (7.9) and adding and subtracting $\int_0^\infty \lambda_t I_t / z_t e^{-rt} dt$ to equation (7.13), we obtain:

$$\eta_0 K_0 = \lambda_0 V_0 + \int_0^\infty \left[\lambda_t I_t / z_t - \eta_t \left[1 - \phi(x_t/I_t)\right] I_t\right] e^{-rt} dt. \tag{7.14}$$

It is useful to note that:

$$\frac{d}{dt}\left[\omega_t I_t e^{-rt}\right] = \left[\dot{\omega}_t I_t + \omega_t x_t - r\omega_t I_t\right] e^{-rt}, \tag{7.15}$$

$$\int_0^\infty \frac{d}{ds}\left[\omega_s I_s e^{-rs}\right] dt = -\omega_0 I_0, \tag{7.16}$$

$$\begin{aligned}\left[\dot{\omega}_t I_t + \omega_t x_t - r\omega_t I_t\right] &= \left\{r\omega_t + \lambda_t / z_t - \eta_t \left[1 - \phi(x_t/I_t)\right] - \eta_t \phi'(x_t/I_t)\left(x_t/I_t\right)\right\} I_t \\ &\quad + \eta_t \phi'(x_t/I_t) x_t - r\omega_t I_t.\end{aligned}$$

Simplifying:

$$[\dot{\omega}_t I_t + \omega_t x_t - r\omega_t I_t] = \{\lambda_t/z_t - \eta_t [1 - \phi(x_t/I_t)]\} I_t. \tag{7.17}$$

Using equations (7.15), (7.16), and (7.17), we have:

$$-\omega_0 I_0 = \int_0^\infty \{\lambda_t/z_t - \eta_t [1 - \phi(x_t/I_t)]\} I_t e^{-rt} dt. \tag{7.18}$$

Using equations (7.14) and (7.18) we obtain:

$$\eta_0 K_0 = \lambda_0 V_0 - \omega_0 I_0.$$

Rearranging this expression gives us:

$$V_0 = \frac{\eta_0}{\lambda_0} K_0 + \frac{\omega_0}{\lambda_0} I_0,$$

$$V_0 = \frac{\eta_0}{\lambda_0} [K_0 + \phi'(x_0/I_0) I_0].$$

7.1.3. Labor adjustment costs

A similar result holds for labor adjustment costs. Suppose that the problem of the firm is given by:

$$\max V_0 = \frac{1}{\lambda_0} \int_0^\infty \lambda_t [F(K_t, N_t) - w_t N_t - I_t/z_t] e^{-rt} dt,$$

$$\dot{K}_t = \left[1 - \phi(\dot{N}_t/N_t)\right] I_t - \delta K_t.$$

Then the value of the firm is equal to:

$$V_0 = \frac{\eta_0}{\lambda_0} \left[K_0 + \phi'(\dot{N}_0/N_0) N_0\right].$$

7.2. Discrete time results

We first state without proof a discrete-time version of the key result in Hayashi (1982) about the relation between average and marginal q. We then analyze the relation between average and marginal q in a model of the firm with CEE adjustment costs.

7.2.1. Hayashi adjustment costs

The firm's problem is given by:

$$V^*(K, A, z, \lambda) = \max \ \lambda [AF(K, N) - wN - I/z] + E_0 \beta V^*(K', A', z', \lambda'),$$

$$K' = \phi(I/K)K + (1-\delta)\,K. \tag{7.19}$$

The firm takes as given the laws of motion for the marginal utility of consumption, the real wage, and the aggregate stock of capital in the economy, $\mathbb{K}$:

$$\begin{aligned} w &= w(A, z, \mathbb{K}), & (7.20) \\ \lambda &= \lambda(A, z, \mathbb{K}), & (7.21) \\ \mathbb{K}' &= \mathbb{K}(A, z, \mathbb{K}). & (7.22) \end{aligned}$$

Marginal q, the value of an additional unit of installed capital is given by: $1/\left[z\phi'(I/K)\right]$.

Define the end-of-period value of the firm as:

$$V(K', A, z, \lambda) = E_0 \beta V^*(K', A', z', \lambda'),$$

The value of the firm can be written as:

$$\frac{V(K', A, z, \lambda)}{K'} = \frac{1}{z\phi'(I/K)}.$$

CEE adjustment costs The value of the firm is given by:

$$V^*(K, I_{-1}, A, z, \lambda) = \max \lambda \left[AF(K, N) - wN - I/z\right] + E_0 \beta V^*(K', I, A', z', \lambda'),$$

$$K' = I\left[1 - \phi\left(\frac{I}{I_{-1}}\right)\right] + (1-\delta)\,K. \tag{7.23}$$

The firm takes as given the law of motion for wages, the aggregate capital stock and the marginal utility of consumption (equations (7.20), (7.21), and (7.22)).

Our main result is summarized in the following proposition.

Proposition 7.2. *The end-of-period value of the firm, $V(K, I_{-1}, A, z, \lambda)$, is equal to:*

$$V(K, I_{-1}, A, z, \lambda) = \frac{\eta}{\lambda}(1-\delta)\,K + I/z + \frac{\eta}{\lambda}\left[\phi'\left(\frac{I}{I_{-1}}\right)\left(\frac{I}{I_{-1}}\right) I\right],$$

where η is the Lagrange multiplier associated with (7.23).

To prove this proposition we start by stating the first-order conditions for I and K':

$$E_0 \beta V_2^*(K', I, A', z', \lambda') = \lambda/z - \eta\left[1 - \phi\left(\frac{I}{I_{-1}}\right)\right] + \eta\phi'\left(\frac{I}{I_{-1}}\right)\left(\frac{I}{I_{-1}}\right), \tag{7.24}$$

$$E_0 \beta V_1^*(K', I, A', z', \lambda') = \eta. \tag{7.25}$$

Optimizing out labor we can rewrite the firm's problem as:

$$V^*(K, I_{-1}, A, z, \lambda) = \max \lambda \left[AF_1 \left[k(w, A), 1\right] K - wN - I/z\right] + E_0 \beta V^*(K', I, A', z'\lambda'),$$

where the function $K/N = k(w, A)$ is given by:

$$AF_2(k(w, A), 1) = w.$$

Define the end-of-period value of the firm as:

$$\bar{V}(K, I_{-1}, A, z, \lambda) = E_0 \beta V^*(K', I, A', z', \lambda').$$

We now use the following proposition, which we prove below:

Proposition 7.3. *$\bar{V}$ is homogeneous of degree one in K and I_{-1}.*

Using this proposition we can write:

$$\bar{V}(K, I_{-1}, A, z, \lambda) = E_0 \beta V_1^*(K', I, A', z', \lambda')K' + E_0 \beta V_2^*(K', I, A', z', \lambda')I.$$

Using (7.24) and (7.25) we have:

$$\bar{V}(K, I_{-1}, A, z, \lambda) = \eta K' + \left\{\lambda/z - \eta \left[1 - \phi\left(\frac{I}{I_{-1}}\right)\right] + \eta \phi'\left(\frac{I}{I_{-1}}\right)\left(\frac{I}{I_{-1}}\right)\right\} I.$$

Using equation (7.23) we can rewrite $\bar{V}(K, I_{-1}, A, z, \lambda)$ as:

$$\bar{V}(K, I_{-1}, A, z, \lambda) = \eta \left(1 - \delta\right) K + \lambda I/z + \eta \phi'\left(\frac{I}{I_{-1}}\right)\left(\frac{I}{I_{-1}}\right) I.$$

The value of the firm measured in consumption units, which we denote as $V(K, I_{-1}, A, z, \lambda)$, is:

$$V(K, I_{-1}, A, z, \lambda) = \bar{V}(K, I_{-1}, A, z, \lambda)/\lambda,$$

$$V(K, I_{-1}, A, z, \lambda) = \frac{\eta}{\lambda}\left(1 - \delta\right) K + I/z + \frac{\eta}{\lambda}\phi'\left(\frac{I}{I_{-1}}\right)\left(\frac{I}{I_{-1}}\right) I.$$

We now prove proposition 7.3. We start by writing the problem in sequence form and deriving the first-order conditions:

$$V_0^* = \max E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left[A_t F(K_t, N_t) - w_t N_t - I_t/z_t\right],$$

subject to (7.23). Optimizing out labor we can re-write the firms problem as:

$$V_0^* = \max E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left\{ A_t F_1 \left[k(w, A), 1 \right] K_t - I_t / z_t \right\}.$$

The first-order conditions for this problem are:

$$\eta_t = E_t \beta \left[\lambda_{t+1} A_{t+1} F_1 \left[k(w_{t+1}, A_{t+1}), 1 \right] + \eta_{t+1}(1-\delta) \right],$$

$$\eta_t / z_t = \eta_t \left[1 - \phi \left(\frac{I_t}{I_{t-1}} \right) \right] - \eta_t \phi' \left(\frac{I_t}{I_{t-1}} \right) \left(\frac{I_t}{I_{t-1}} \right) + E_t \beta \eta_{t+1} \phi' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2.$$

Consider a contingent sequence for K_{t+1} and I_t which is a solution to the first-order conditions. Now suppose we multiply the initial conditions, K_0 and I_{-1}, by a constant, χ. We conjecture that the new solution is given by the old contingent sequence for K_{t+1} and I_t multiplied by χ. It is easy to verify that this solution satisfies the first-order conditions of the firm's problem. As a result, both $V^*(K, I_{-1}, A, \lambda)$ and $V(K, I_{-1}, A, \lambda)$ are homogeneous of degree one in K and I_{-1}.

TABLE 1: ROBUSTNESS ANALYSIS

One-sector model

	News A	News z
Maximum γ	0.650	0.400
Minimum adjustment costs, $\phi''(1)$	0.370	0.400
Minimum elasticity of labor supply $(1/(\theta-1))$	0.111	0.111
Maximum elasticity of utilization	2.500	5.000

Two-sector model

	Contemporaneous shocks			News shocks		
	A	z^c	z^i	A	z^c	z^i
Maximum γ	0.600	1.000	0.110	0.009	0.006	0.006
Minimum adjustment costs, $\phi''(1)$	0.010	0.010	0.010	1.100	1.000	1.100
Minimum elasticity of labor supply $(1/(\theta-1))$	0.256	0.001	1.000	1.667	1.667	1.667
Maximum elasticity of utilization	infinity	infinity	2.800	0.300	0.300	0.250

TABLE 2: BUSINESS CYCLE MOMENTS

	DATA			MODEL		
	1947-2004	1947-1983	1983-2004	No signal	Signal with Livingston-survey precision	Perfect signal
Std. Dev. Output	1.56	1.88	0.97	1.10	1.00	0.94
Std. Dev. Hours	1.51	1.88	1.00	0.78	0.71	0.67
Std. Dev. Investment	4.84	5.41	3.69	3.45	3.33	3.30
Std. Dev. Consumption	1.11	1.22	0.75	0.81	0.75	0.73
Correlation Output and Hours	0.86	0.88	0.87	1.00	1.00	1.00
Correlation Output and Investment	0.89	0.75	0.91	0.97	0.93	0.85
Correlation Output and Consumption	0.77	0.68	0.75	0.94	0.92	0.89
Sum of 4 coefficents in AR(4)	0.77	0.65	0.86	0.71	0.78	0.80
Number of Recessions	14			9	9	9

Figure 1: Investment, earnings growth forecasts, and realized earnings

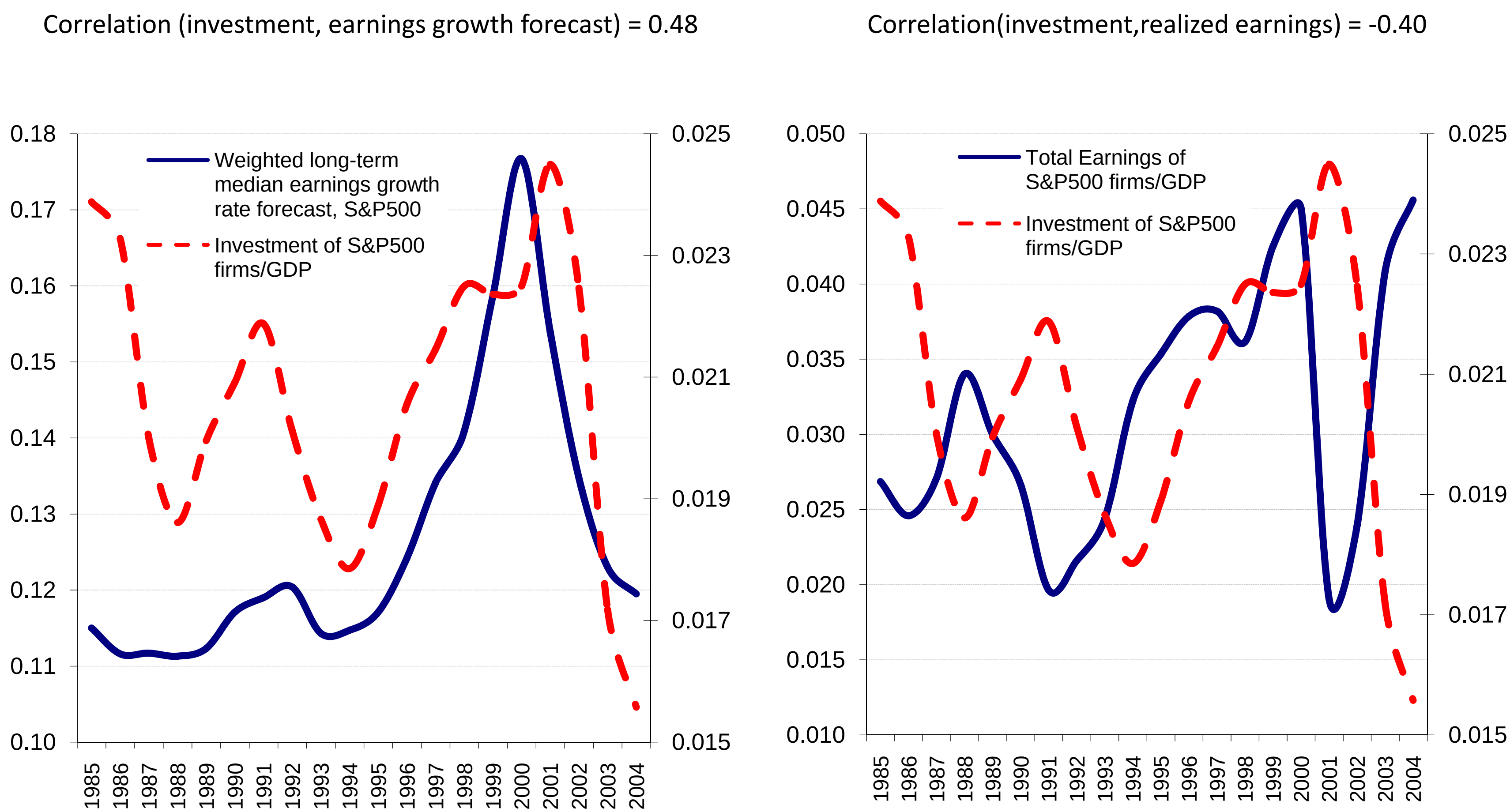

Figure 2: One-sector model, response to news shocks

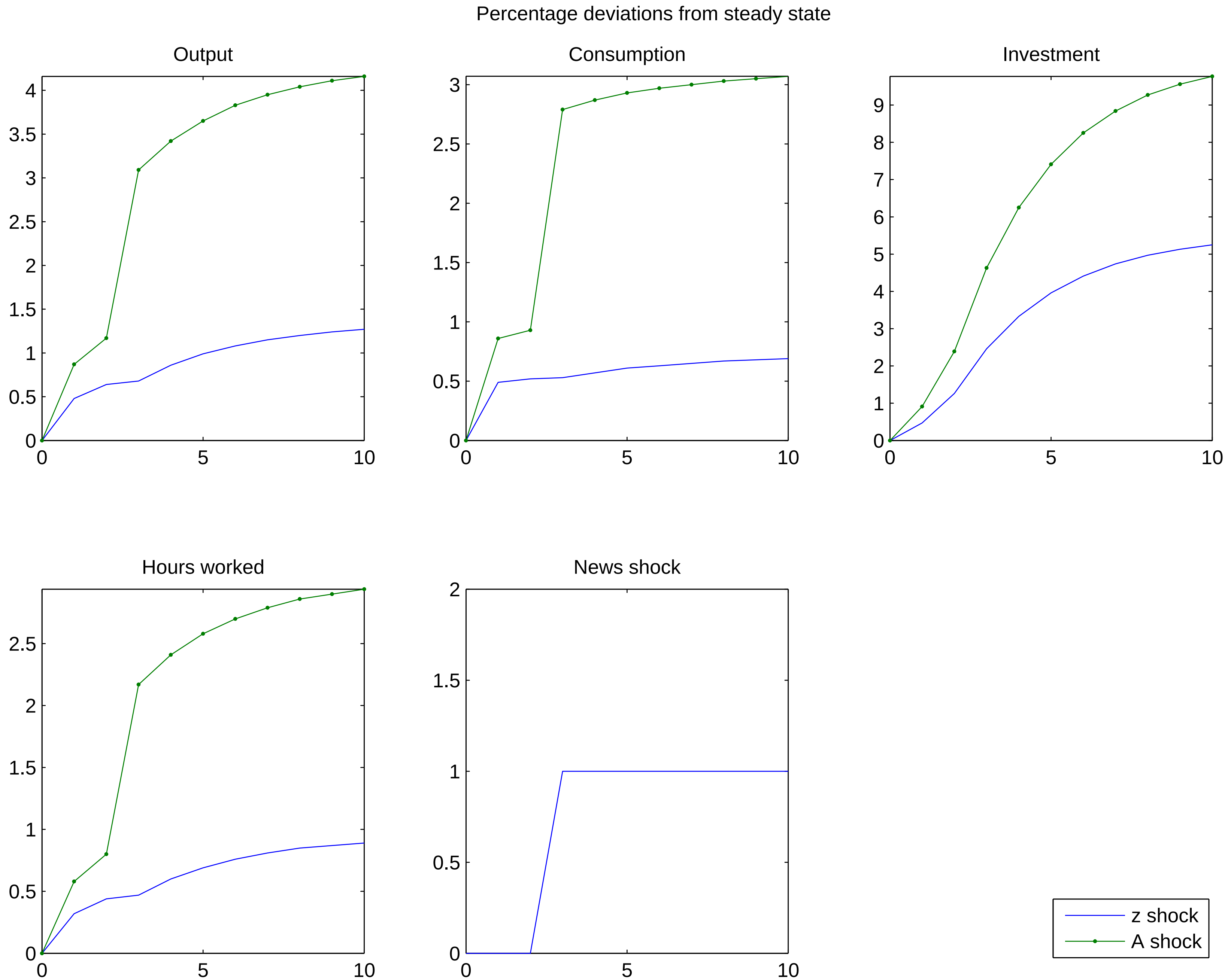

Figure 3: Wealth effects on the labor supply of a one percent permanent real wage increase

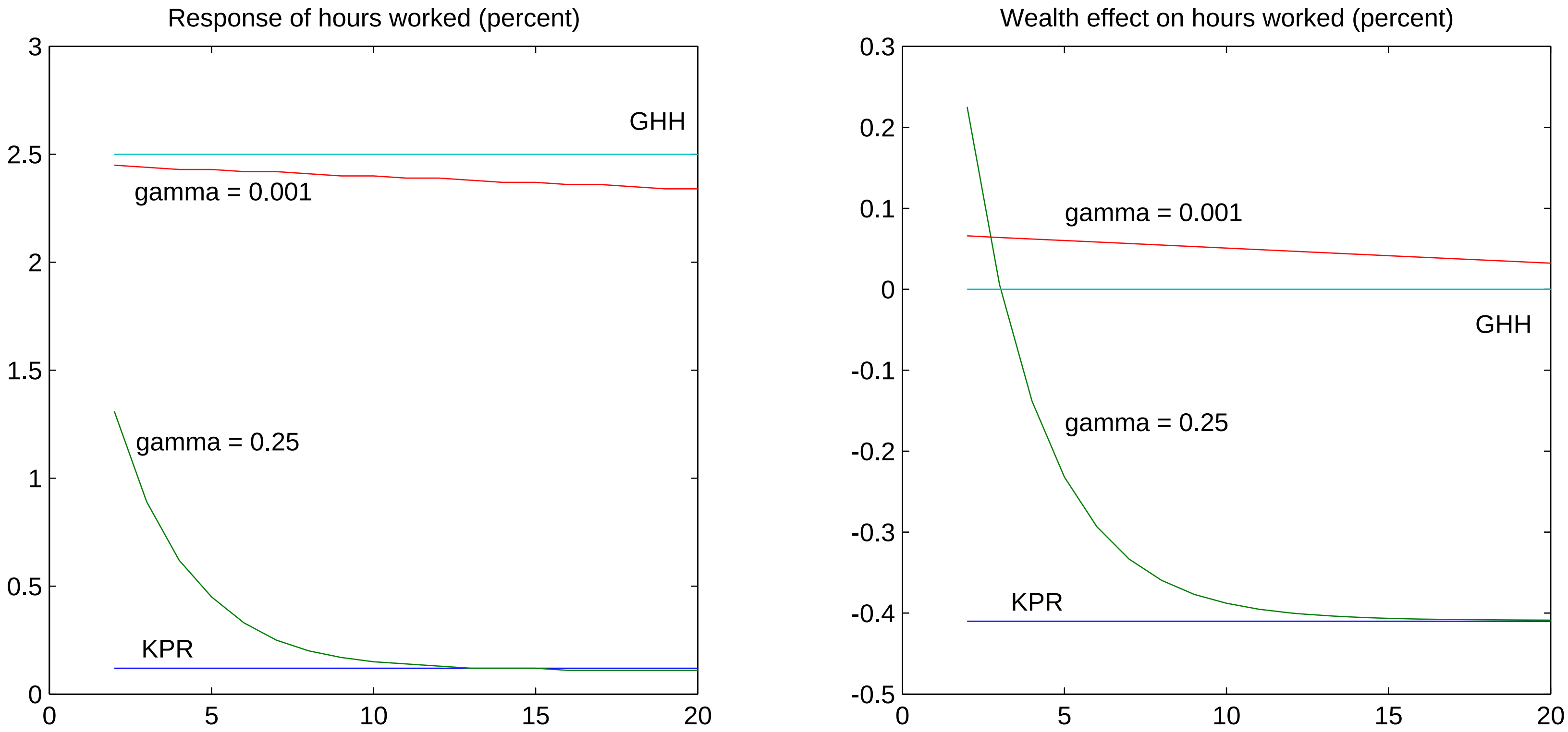

Figure 4: Effects of contemporaneous shocks

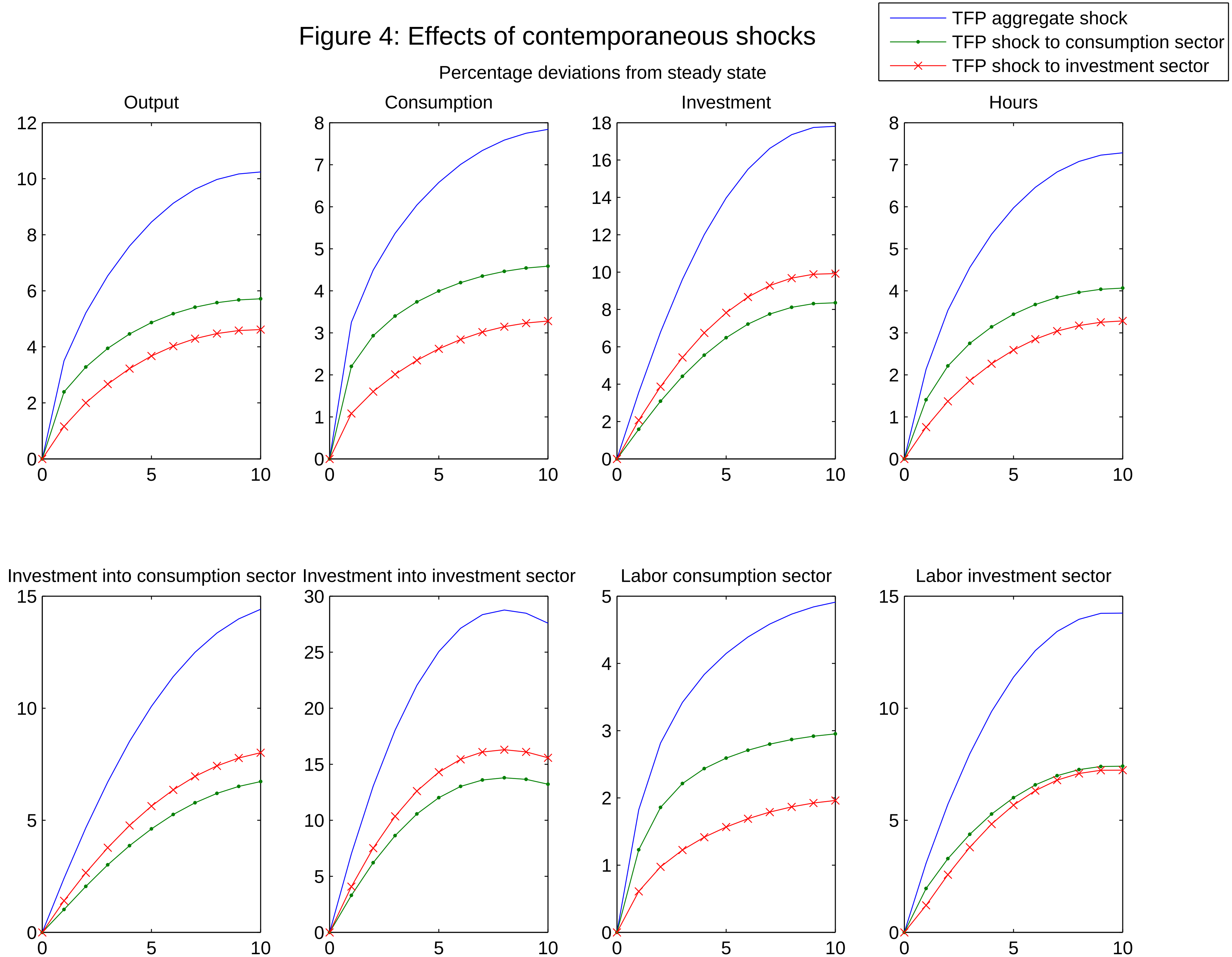

Figure 5: Effects of news shocks

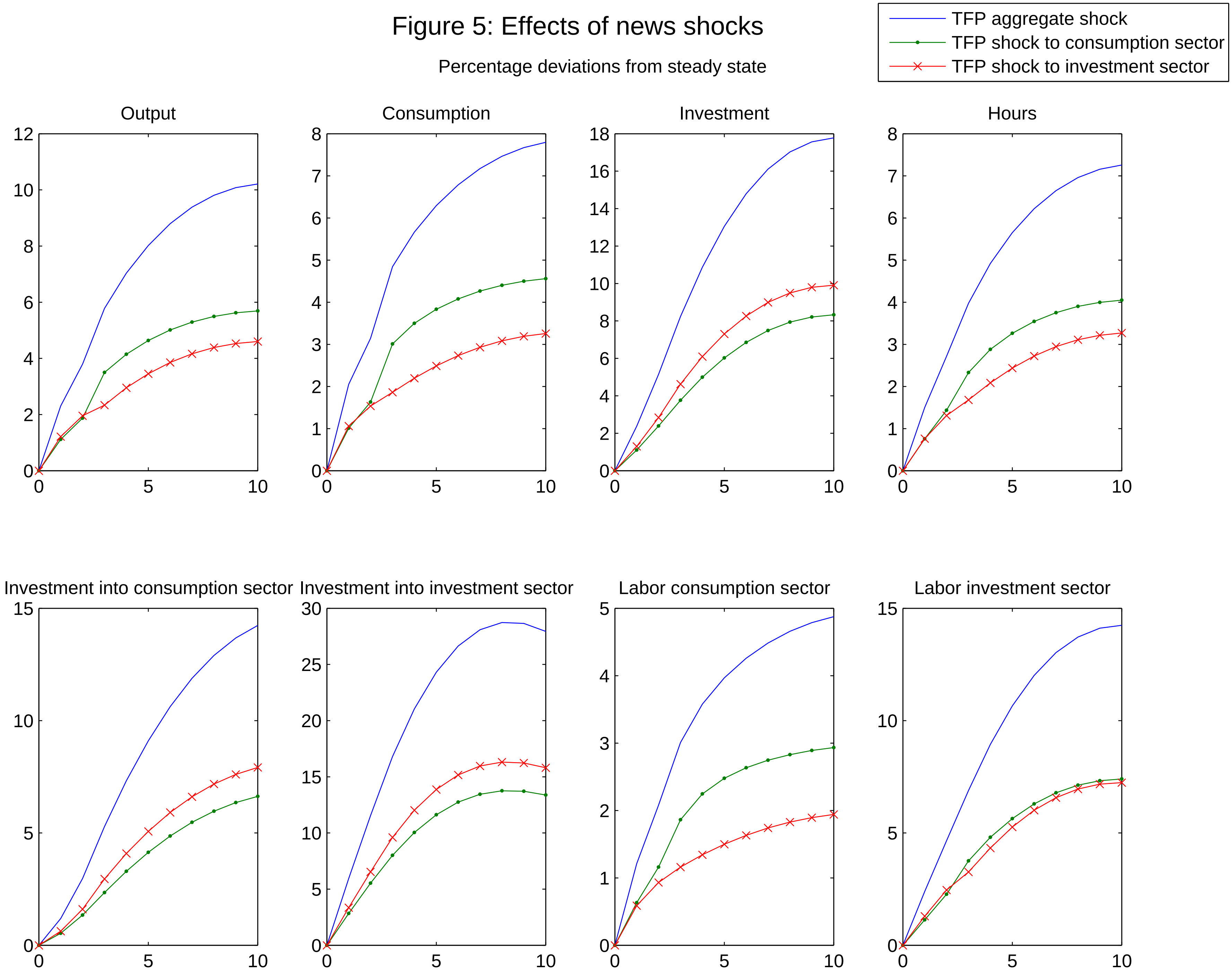

Figure 6: Average recession in the model and in U.S. data