Revisiting the 'Productivity-Hours Puzzle' in the RBC Paradigm: The Role of Investment Adjustment Costs

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Abstract

Conventional RBC models have been heavily criticized for their inability to generate the estimated negative correlations of hours and productivity in response to technology shocks ('productivity-hours puzzle'). In this paper we show that by just enhancing the standard framework with investment adjustment costs can resolve the 'productivity-hours puzzle'.

JEL classification: E22, E32.

Keywords: technology shocks; productivity-hours puzzle; investment adjustment costs; wealth effect.

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1 Introduction

The Real Business Cycle (RBC) paradigm, exemplified by the seminal work of Kydland and Prescott (1982), indicates that technology shocks in the form of disturbances in Total Factor Productivity (TFP) are a central source of macroeconomic fluctuations. Yet, the RBC approach and the associated pivotal role of shocks have been heavily criticized due to their inability in generating plausible responses of some key aggregates. In particular, Galí (1999) using structural VARs and identifying TFP shocks as the only disturbance that changes labor productivity in the long run, finds that in the short run hours fall in response to a positive TFP shock ('productivity-hours puzzle').[1] This finding comes in sharp contrast with the implications of standard RBC models (see, e.g., King et al., 1988; King, 1991), leading to versions of the RBC model augmented with monopolistic competition or nominal frictions in wages and prices, broadly known as the New Keynesian models, which have been more successful in addressing the 'productivity-hours puzzle'.

In this note we show that the puzzle can be resolved within an otherwise standard RBC model by postulating adjustment costs in the capital accumulation process. More specifically, following Christiano et al. (2005), we adopt the concept of convex adjustment costs on investment, which are associated with changes in the level of investment and have become a widely-used feature in recent dynamic general equilibrium models.[2] To our knowledge, no existing study has isolated the role of convex investment adjustment costs in a frictionless RBC setup in order to examine the dynamic responses of the model in conjunction with the 'productivity-hours puzzle'. Our results indicate that the presence of investment adjustment costs can generate a fall in hours after a TFP shock. Intuitively, adjustment costs mitigate the impact effect of a TFP shock on the capital stock and, due to production complementarities, labor and utilization increase relatively less on equilibrium. The negative impact of adjustment costs on hours is amplified by the wealth effect in preferences, as agents further increase their consumption and decrease their labor supply.

[1] Galí's empirical results have been the center of a vast empirical literature and were recently confirmed by, among others, Ravn and Simonelli (2008) and Canova et al. (2010). Cantore et al. (2011) show that the response of hours to productivity shocks is time varying due to changes in the degree of factor substitution.

[2] See Groth and Khan (2010) for a short review.

2 Model and parameterization

Our core economic environment is a standard generalized RBC setup with temporary and permanent technology disturbances, augmented with investment adjustment costs. Consider an economy of infinitely lived individuals with preferences over goods and leisure represented by:

$$U(C_t, h_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{X_t^{1-\sigma} h_t^{1+\zeta}}{1+\zeta} \tag{2.1}$$

where C_t and h_t denote individual consumption and hours worked respectively, and σ, ζ, χ are positive parameters. The household owns the capital stock and receives income from working at a wage rate w_t and from renting at a rate r_t the effective capital stock (capital services), $U_t K_t$, where U_t is the utilization rate of the capital stock K_t, to the firm (Kydland and Prescott, 1988; Bils and Cho, 1994):

$$C_t + I_t \leqslant w_t h_t + r_t U_t K_t \tag{2.2}$$

The law of motion for capital with adjustment costs on investment is given by:

$$I_t = K_{t+1} - \left[1 - \delta U_t^{\phi}\right] K_t + I_{t-1} \frac{b}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \tag{2.3}$$

Following Christiano et al. (2005), the term $\frac{b}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$ with $b > 0$ captures adjustment costs on investment, I_t. The term δU_t^{ϕ} with $\delta, \phi > 0$ follows Burnside and Eichenbaum (1996) and captures the endogenous capital depreciation rate, which depends on capital utilization and is important for the propagation of productivity shocks (Greenwood et al., 2000).[3]

On the production side of the economy, there is one final good produced according to:

$$Y_t = A_t \left(U_t K_t\right)^{1-\alpha} \left(X_t h_t\right)^{\alpha} \tag{2.4}$$

where A_t represents temporary changes in productivity and X_t is a labor-augmenting shock that follows a logarithmic random walk with drift, $X_t = X_{t-1} \exp(\theta + v_t)$.

The aggregate resource constraint of the economy is given by $C_t + I_t = Y_t$.

[3] Variable capital utilization is included for completeness and does not affect our baseline results. If anything, utilization could move our results to the opposite direction, since it increases the marginal product of labor and the real wage rate after a TFP shock, thus inducing a rise in the labor supply.

We parameterize our benchmark model assigning values in line with the existing literature or based on US data (the summary of the parameters is given in Table 1). The discount factor β is calibrated such that the steady-state annualized real interest rate is equal to 2%. We fix the inverse of the Frisch elasticity ζ to 1.25, which corresponds to an elasticity of the labor supply of 0.8. Parameter χ is fixed so that the steady-state share of hours is 0.3. The risk aversion parameter σ is initially set to 1; as the values adopted in the literature vary in the interval [0,6], we will investigate the sensitivity of our results to this parameter. The share of labor α is set to 0.65. The quarterly gross trend growth rate of technology is set to 0.34% (Burnside and Eichenbaum, 1996). The steady-state ratio investment to capital ratio is set to 3%, in line with the average quarterly rate in US data for investment in machinery and equipment (Becker and Gray, 2009). The values of δ, ϕ, $\frac{K}{Y}$, $\frac{I}{Y}$ and $\frac{C}{Y}$ are in turn derived from the steady-state solution, whereas the steady-state utilization rate is set equal to 1. Persistence of the temporary productivity shock, ρ_a is set to 0.85, while the labor-augmenting technology shock is assumed to have no persistence. The standard deviations of shocks are normalized to 0.01.

Concerning the parameter on investment adjustment costs, b, which is obviously a key parameter for evaluating the cyclical properties of the model, there are only scant estimates of its magnitude. Eberly et al. (2011) report a value of b in the vicinity of 2, whereas Groth and Khan (2010) estimate that investment adjustment costs are small. Given the crucial role of the degree of adjustment costs, we consider values for parameter b in the interval [0,20].

3 Dynamic responses of hours and the role of adjustment costs

3.1 Baseline model

The dynamics of the model are obtained by the log-linearized equilibrium conditions around the steady state (the detailed solution of the model is given in the Technical Appendix to the paper). We show the impulse response functions to a temporary productivity shock (A_t) and a labor-augmenting technology shock (v_t) focusing on the effects triggered by adjustment costs. For this reason we first report results for the benchmark case in which adjustment costs are suppressed from the model economy ($b = 0$), and for $b = 8$ and $b = 20$.

In the case of no adjustment costs ($b = 0$ in Figure 1) the standard results of the RBC model are obtained (see e.g. King and Rebelo, 1999). The response of hours to a productivity shock is governed by the intertemporal substitution of current for future consumption. The early, strongly positive, part of the impact response of hours is dominated by the rise in the marginal product of labor and the desirability of work effort due to the high returns on savings. The income effect is smaller in the case of a temporary shock and there is greater incentive to substitute intertemporally, since the current wage is high relative to future wages. Given the rise in income, both consumption and investment increase. In turn, due to complementarities in production, utilization and capital services rise as well. In the case of a temporary shock the propagation mechanism is rather weak: all variables eventually return to their base levels. In the case of a permanent shock, the series exhibit higher persistence. Labor supply is higher for a prolonged period of time and the additional output is consumed and invested, generating more persistent responses.

The picture changes starkly when investment adjustment costs are considered (see Figure 1 for $b = 8$ and $b = 20$). The rise in productivity in now associated with a smaller increase in output. Agents find it costly to invest in the first period and the rise in output is transferred into current consumption. In turn, this affects the consumption-leisure choice and the marginal value of leisure increases, leading to a fall in hours and a negative relationship with output. In the case of a temporary shock, investment and capital utilization are virtually unaffected, whereas consumption returns eventually to the baseline level. In the case of a permanent shock, investment starts to rise leading to a proportionate decrease in the higher consumption level. Utilization and capital services tend thus to rise and, along with a gradual rise of the labor supply fuel output.

3.2 Elasticity of intertemporal substitution

Given that the magnitude of the elasticity of intertemporal substitution affects the pattern of the intertemporal consumption allocation, we analyze the sensitivity of our results to changes in σ. The results on output, hours and consumption for values of σ in the range between 1 and 6 are depicted in Figure 2 for the temporary and the permanent technology shock with $b = 8$. In response to a temporary shock the negative correlation between output and hours persists and the results are only quantitatively affected. As σ increases, agents are less willing to transfer consumption to the future and current consumption is relatively higher. This induces a stronger substitution effect with leisure, triggering a higher fall of hours and, consequently, dampens the hump-shaped effect of the productivity shock on output. In response to the permanent shock instead the impact response of hours becomes lower as σ increases and turns positive for high enough values of σ. This effect is driven by a wealth effect, as consumption is less affected by the shock for higher values of σ. In the next subsection we further explore the role of the wealth effect for our results.

3.3 Wealth effect

An important feature for the response of hours to productivity shocks is the wealth effect in preferences, which generates a rise in consumption and a fall in labor supply. When the accumulation of capital is subject to investment adjustment costs agents further increase their consumption and decrease their labor supply on impact anticipating the increase in output after the costs of adjustment on capital are removed. Following Galí (2011), we modify preferences given by (2.1) to allow for smaller wealth effects as follows:

$$U(C_t, h_t) = \Theta_t \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\zeta}}{1+\zeta} \tag{3.1}$$

where $\Theta_t \equiv \overline{C}_t^{\sigma} / J_t$ with $J_t = J_{t-1}^{\gamma} \overline{C}_t^{1-\gamma}$ and $\overline{C}_t$ denoting aggregate consumption (taken as given by each individual household). Parameter $0 \leq \gamma \leq 1$ captures the impact of changes in consumption on the marginal rate of substitution; as γ approaches unity, changes in consumption will have smaller effects on labor supply.

Figure 3 displays the impulse responses for increasing values of parameter γ, which imply a smaller wealth effect ($b = 20$). The responses of hours to both types of shocks are an increasing function of γ. This is not surprising since the closer γ is to unity the more labor supply decisions are based on the marginal product of labor, which increases after a TFP shock, accompanied by a lower wealth effect. The rise in labor due to complementarities raises capital utilization and further boosts output and consumption. As a result, the fall in hours originating from the presence of adjustment costs is undone by the reductions in the size of the wealth effect in the labor supply decision.

4 Conclusions

The goal of this note is to examine the implications of adjustment costs on investment in the context of the well-documented 'productivity-hours puzzle' in RBC modelling. We show that incorporating investment adjustment costs in the standard RBC model can generate negative co-movements between hours and productivity. Investment adjustment costs can thus provide a simple and straightforward resolution to the 'productivity-hours puzzle' and should be routinely included in dynamic stochastic general equilibrium models.

We stress that other models have provided a similar picture, using however, along with adjustment costs, richer structures that include real and nominal frictions among many other features. Our findings are consistent with any origin of this type of frictions, like time-to-build, installation, planning and sunk costs, delivery lags and learning, investment irreversibility, and borrowing constraints. This reinforces the importance of the empirical regularities reported here and opens a route for further research in the potential sources of rigidities in the capital accumulation process and their implications for the behavior of key aggregates.

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A Appendix: The Model with Investment Adjustment Costs

A.1 Households and firms

The households maximize the Lagrangian:

$$\begin{aligned}\mathcal{L} &= \sum_{t=0}^{\infty}\beta^t\left[\frac{C_t^{1-\sigma}}{1-\sigma}-\chi\frac{X_t^{1-\sigma}h_t^{1+\zeta}}{1+\zeta}\right]+\Lambda_t\left\{w_th_t+r_tU_tK_t-C_t-I_t\right\}\\ &\quad+\Omega_t\left\{Z_tI_t-\frac{b}{2}Z_{t-1}I_{t-1}\left(\frac{I_t}{I_{t-1}}-1\right)^2-K_{t+1}+\left(1-\delta U_t^{\phi}\right)K_t\right\}\end{aligned}$$

where $\Theta_t = \frac{\bar{C}_t^{\sigma}}{J_t}$ and $J_t = J_{t-1}^{\gamma}\bar{C}_t^{1-\gamma}$ as described in the text and $0 < \beta < 1$. The first-order conditions are given by:

$$\frac{\partial\mathcal{L}}{\partial C_t} = \frac{(1-\sigma)\,C_t^{-\sigma}}{(1-\sigma)} - \Lambda_t = 0 \tag{A.1}$$

$$\frac{\partial\mathcal{L}}{\partial h_t} = -\frac{\chi X_t^{1-\sigma}(1+\zeta)\,h_t^{\zeta}}{(1+\zeta)} + \Lambda_t w_t = 0 \tag{A.2}$$

$$\frac{\partial\mathcal{L}}{\partial U_t} = \Lambda_t r_t K_t - \Omega_t\delta\phi U_t^{\phi-1}K_t = 0 \tag{A.3}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial I_t} &= -\Lambda_t+\Omega_t\left\{1-bI_{t-1}\left(\frac{I_t}{I_{t-1}}-1\right)\frac{1}{I_{t-1}}\right\}\\ &\quad+\beta\Omega_{t+1}\left\{-\frac{b}{2}\left[\left(\frac{I_{t+1}}{I_t}-1\right)^2+I_t2\left(\frac{I_{t+1}}{I_t}-1\right)\left(-\frac{I_{t+1}}{I_t^2}\right)\right]\right\}=0\end{aligned} \tag{A.4}$$

$$\frac{\partial\mathcal{L}}{\partial K_{t+1}} = -\Omega_t + \beta\Lambda_{t+1}r_{t+1}U_{t+1} + \beta\Omega_{t+1}\left(1-\delta U_{t+1}^{\phi}\right) = 0 \tag{A.5}$$

On the supply side of the economy, firms maximize profits given by:

$$\Pi_t = Y_t - (w_th_t + r_tU_tK_t)$$

subject to the technology constraint

$$Y_t = A_t\,(U_tK_t)^{1-\alpha}\,(X_th_t)^{\alpha} \tag{A.6}$$

The first-order conditions w.r.t. h_t and $U_t K_t$ are:

$$w_t = \alpha \frac{Y_t}{h_t} \tag{A.7}$$

$$r_t = (1-\alpha) \frac{Y_t}{U_t K_t} \tag{A.8}$$

A.2 Model solution and equilibrium conditions

From (A.1) and (A.2) we obtain the labor supply function:

$$w_t = \chi X_t^{1-\sigma} h_t^{\zeta} C_t^{\sigma} \tag{A.9}$$

Equilibrium in the labor market is given by (A.9) and (A.7):

$$\alpha \frac{Y_t}{h_t} = \chi X_t^{1-\sigma} h_t^{\zeta} C_t \tag{A.10}$$

whereas from (A.3), (A.8) and (A.1) we get that:

$$\Omega_t = \frac{C_t^{-\sigma} (1-\alpha) Y_t}{\delta \phi U_t^{\phi} K_t} \tag{A.11}$$

From the last equation, the first-order conditions for consumption and investment, and (A.8) we obtain:

$$\frac{C_t^{-\sigma} (1-\alpha) Y_t}{\delta \phi U_t^{\phi} K_t} = \beta C_{t+1}^{-\sigma} (1-\alpha) \frac{Y_{t+1}}{K_{t+1}} \left[1 + \frac{1-\delta U_{t+1}^{\phi}}{\delta \phi U_{t+1}^{\phi}} \right] \tag{A.12}$$

Combining (A.11) and (A.1) with (A.4), we get:

$$\begin{aligned} C_t^{-\sigma} &= \frac{C_t^{-\sigma} (1-\alpha) Y_t}{\delta \phi U_t^{\phi} K_t} \left\{ 1 - b I_{t-1} \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{1}{I_{t-1}} \right\} \\ &\quad + \beta b \frac{C_{t+1}^{-\sigma} (1-\alpha) Y_{t+1}}{\delta \phi U_{t+1}^{\phi} K_{t+1}} \left\{ -\frac{1}{2} \left(\frac{I_{t+1}}{I_t} - 1 \right)^2 + \left(\frac{I_{t+1}}{I_t} - 1 \right) \frac{I_{t+1}}{I_t} \right\} \end{aligned} \tag{A.13}$$

Equations (A.10), (A.12), (A.13) together with (A.6), the capital accumulation equation $I_t = K_{t+1} - \left[1 - \delta U_t^{\phi}\right] K_t + I_{t-1} \frac{b}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2$, and the aggregate resource constraint $C_t + I_t = Y_t$

describe the equilibrium of the economy. Adjusting all non-stationary variables for growth $X_t = X_{t-1}\exp(\theta + v_t)$ and defining $\omega_t \equiv [\exp(\theta + v_t)]$ we obtain:

$$\alpha \frac{y_t}{h_t} = \chi h_t^{\zeta} c_t^{\sigma} \tag{A.14}$$

$$c_t^{-\sigma} = \frac{c_t^{-\sigma}(1-\alpha)\,y_t}{\delta\phi U_t^{\phi} k_t}\omega_t \left[1 - b\left(\frac{i_t}{i_{t-1}}\omega_t - 1\right)\right] \tag{A.15}$$
$$+\beta b \frac{c_{t+1}^{-\sigma}(1-\alpha)\,y_{t+1}}{\delta\phi U_{t+1}^{\phi} k_{t+1}} [\omega_{t+1}]^{1-\sigma} \left[-\frac{1}{2}\left(\frac{i_{t+1}}{i_t}\omega_{t+1} - 1\right)^2 + \left(\frac{i_{t+1}}{i_t}\omega_{t+1} - 1\right)\frac{i_{t+1}}{i_t}\omega_{t+1})\right]$$

$$c_t^{-\sigma}\frac{(1-\alpha)\,y_t}{\delta\phi U_t^{\phi} k_t}\omega_t\,[\omega_{t+1})]^{1-\gamma} = \beta c_{t+1}^{-\sigma}(1-\alpha)\,\omega_{t+1}\frac{y_{t+1}}{k_{t+1}}\left[1 + \frac{\left(1 - \delta U_{t+1}^{\phi}\right)}{\delta\phi U_{t+1}^{\phi}}\right] \tag{A.16}$$

$$i_t - \frac{b}{2} i_{t-1}\,[\omega_t)]^{-1}\left(\frac{i_t}{i_{t-1}}\omega_t - 1\right)^2 = k_{t+1} - \left(1 - \delta U_t^{\phi}\right) k_t\,[\omega_t]^{-1} \tag{A.17}$$

$$y_t = A_t\left(U_t k_t\,[\omega_t]^{-1}\right)^{1-\alpha} h_t^{\alpha} \tag{A.18}$$

$$c_t + i_t = y_t \tag{A.19}$$

Equations (A.14)-(A.19) describe the steady state of the model adjusted for growth. In turn, the following parameters are determined from (A.15), (A.16) and (A.17) respectively:

$$\frac{y}{k} = \frac{\delta\phi}{(1-\alpha)\left\{\omega\left[1 - b\,(\omega - 1)\right] + \beta b\frac{1}{2}\left(\omega^2 - 1\right)\right\}} \tag{A.20}$$

$$\phi = \frac{\omega - \beta\,(1-\delta)}{\delta\beta} \tag{A.21}$$

$$\delta = \left[\omega - \frac{b}{2}\,(\omega - 1)^2\right]\frac{i}{k} - \omega + 1 \tag{A.22}$$

A.3 Log-linearization

Defining $\omega \equiv \exp(\theta + v)$ and $\Xi \equiv \frac{(1-\alpha)y}{\delta\phi k}$, the following system of log-linearized equations is obtained:

$$\hat{y}_t - \hat{h}_t - \sigma\hat{\hat{c}}_t = \zeta\hat{h}_t \tag{A.23}$$

$$
\begin{aligned}
& -\sigma\left\{1-\Xi\omega\left[1-b\left(\omega-1\right)\right]\right\}\hat{c}_t \\
= \;& \Xi\omega\left[1-b\left(\omega-1\right)\right]\left(\hat{y}_t-\hat{k}_t-\phi\hat{U}_t\right) \\
& -\beta b\sigma\Xi\left[\left(\omega-1\right)\omega-\frac{1}{2}\left(\omega-1\right)^2\right]\hat{c}_{t+1} \\
& +\beta b\Xi\omega^{1-\sigma}\frac{1}{2}\left(\omega^2-1\right)\left(\hat{y}_{t+1}-\hat{k}_{t+1}-\phi\hat{U}_{t+1}\right) \\
& -b\Xi\omega^2\left(1+\beta\omega^{1-\sigma}\right)\hat{\imath}_t+b\Xi\omega^2\hat{\imath}_{t-1}+\beta b\Xi\omega^{3-\sigma}\hat{\imath}_{t+1} \\
& +\Xi\omega\left[1-b\left(2\omega-1\right)\right]\hat{v}_t+\beta b\Xi\omega^{1-\sigma}\left[\frac{1}{2}\left(1-\sigma\right)\left(\omega^2-1\right)+\omega^2\right]\hat{v}_{t+1} \qquad \text{(A.24)}
\end{aligned}
$$

$$
\begin{aligned}
& -\sigma\left(\hat{c}_t-\hat{c}_{t+1}\right)+\hat{y}_t-\phi\hat{U}_t-\hat{k}_t+\hat{v}_t \qquad \text{(A.25)} \\
= \;& \hat{y}_{t+1}-\hat{k}_{t+1}+\left(1-\sigma\right)\hat{v}_{t+1}-\frac{\phi}{\delta\phi+\left(1-\delta\right)}\hat{U}_{t+1}
\end{aligned}
$$

$$
\begin{aligned}
& \frac{i}{k}\omega\left[1-b(\omega-1)\right]\hat{\imath}_t+\frac{i}{k}b\left(\omega-1\right)\frac{\omega+1}{2}\hat{\imath}_{t-1} \qquad \text{(A.26)} \\
& -\frac{i}{k}b\left(\omega-1\right)\frac{\omega+1}{2}\hat{v}_t=\omega\hat{k}_{t+1}-\left(1-\delta\right)\hat{k}_t+\delta\phi\hat{U}_t+\left(1-\delta\right)\hat{v}_t
\end{aligned}
$$

$$
\hat{y}_t=\hat{A}_t+\left(1-\alpha\right)\hat{U}_t+\left(1-\alpha\right)\hat{k}_t-\left(1-\alpha\right)\hat{v}_t+\alpha\hat{h}_t \qquad \text{(A.27)}
$$

$$
\frac{c}{y}\hat{c}_t+\frac{i}{y}\hat{\imath}_t=\hat{y}_t \qquad \text{(A.28)}
$$

$$
\hat{A}_t=\rho_a\hat{A}_{t-1}+\varepsilon_t^a \qquad \text{(A.29)}
$$

$$
\hat{v}_t=\rho_v\hat{v}_{t-1}+\varepsilon_t^v \qquad \text{(A.30)}
$$

where hatted variables denote log-deviations from their steady-state values. Equations (A.23) to (A.30) form the set of log-linearized equations for the model with investment adjustment costs.

Table 1. Baseline calibration

Parameters	Description	Value
U	steady-state utilization rate	1
h	steady-state hours	0.3
ζ	inverse of Frisch elasticity	1.25
σ	risk aversion	1
γ	wealth effect	0
b	degree of adjustment costs	[0,20]
ω	gross trend growth rate of technology	1.0034
α	share of labor	0.65
i/k	investment to capital ratio	0.03
β	discount factor	$(1.02)^{-1/4}$
ρ_a	persistence of A shock	0.85
ρ_v	persistence of v shock	0.0
	Parameters values when $b = 0$	
δ	depreciation rate	0.027
ϕ	elasticity of depreciation to changes in utilization	1.31
k/y	capital/output ratio	10
i/y	investment/output ratio	0.30
c/y	consumption/output ratio	0.70

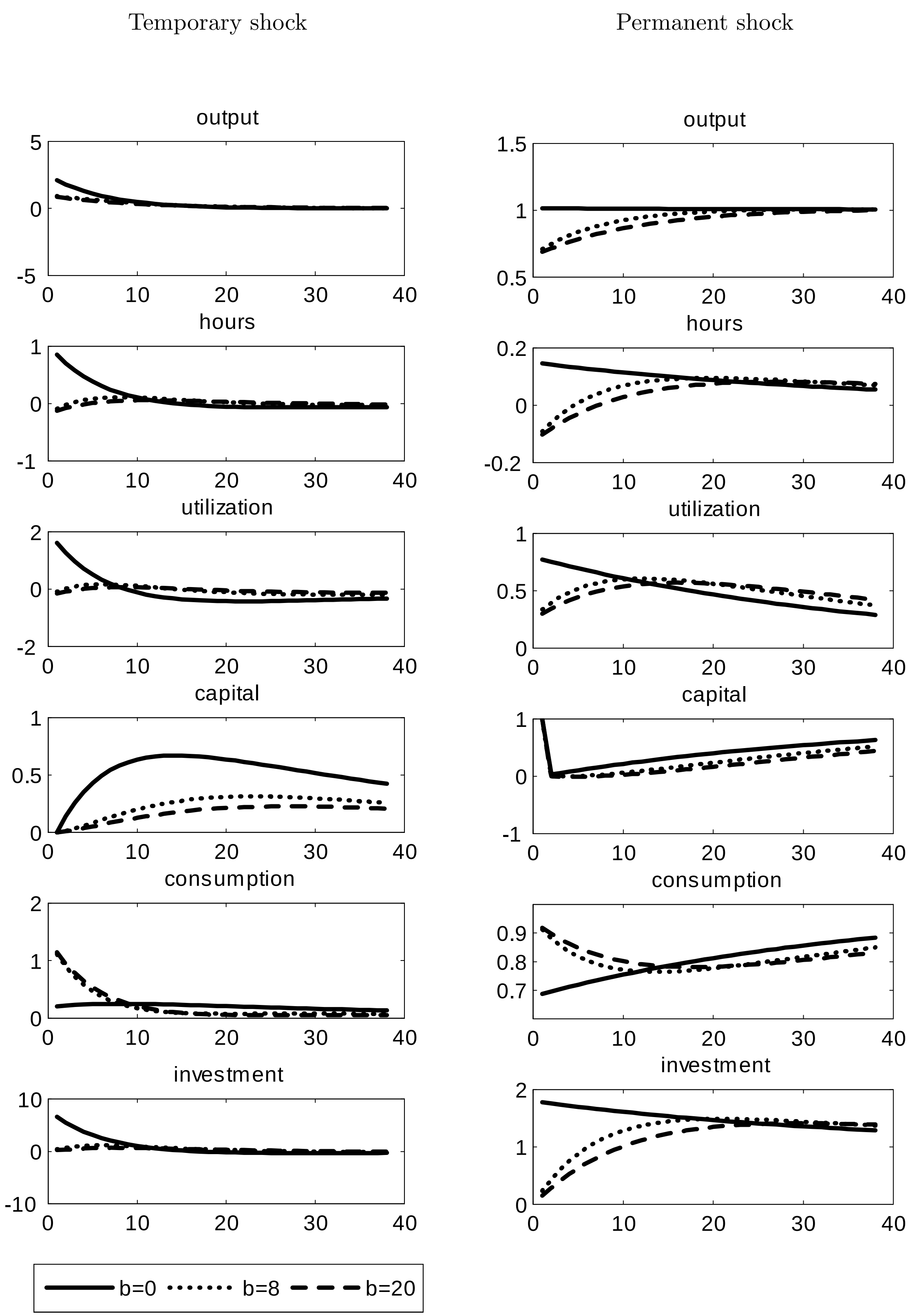

Figure 1. Impulse responses of RBC model with investment adjustment costs.

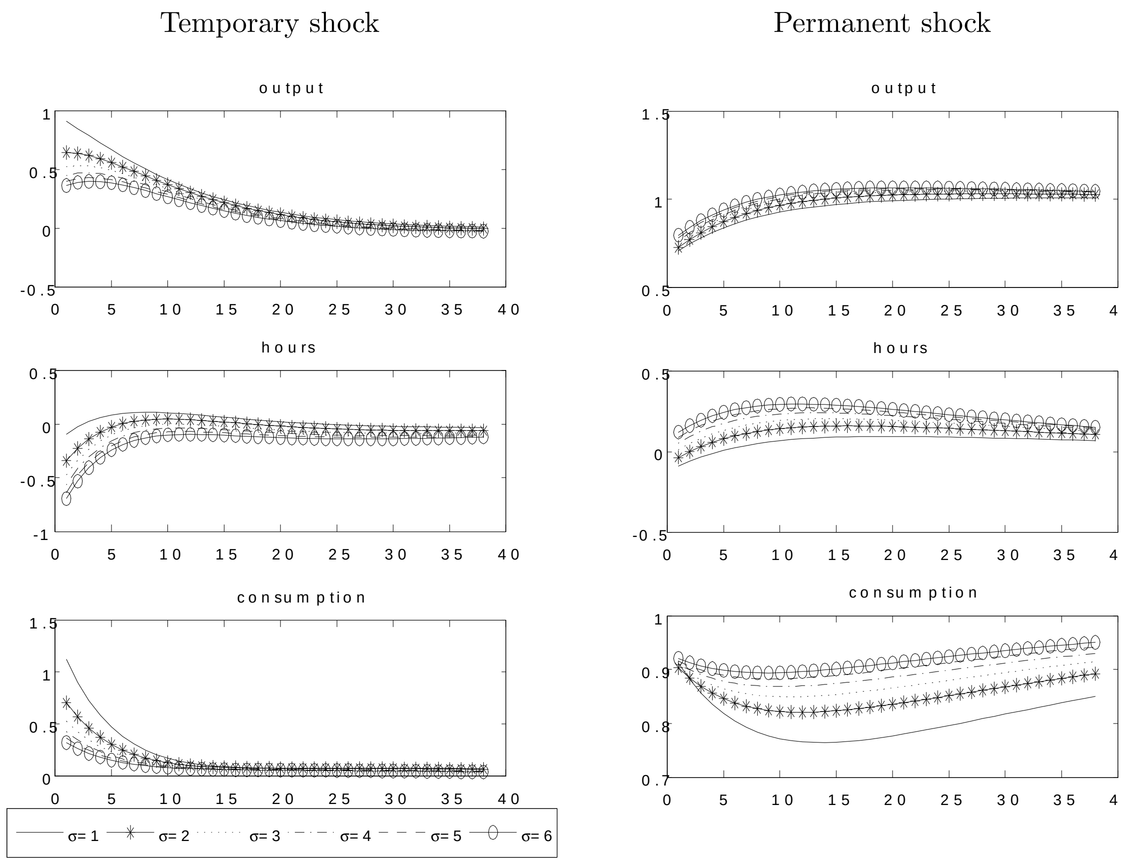

Figure 2. Sensitivity analysis to values of σ ($b = 8$).

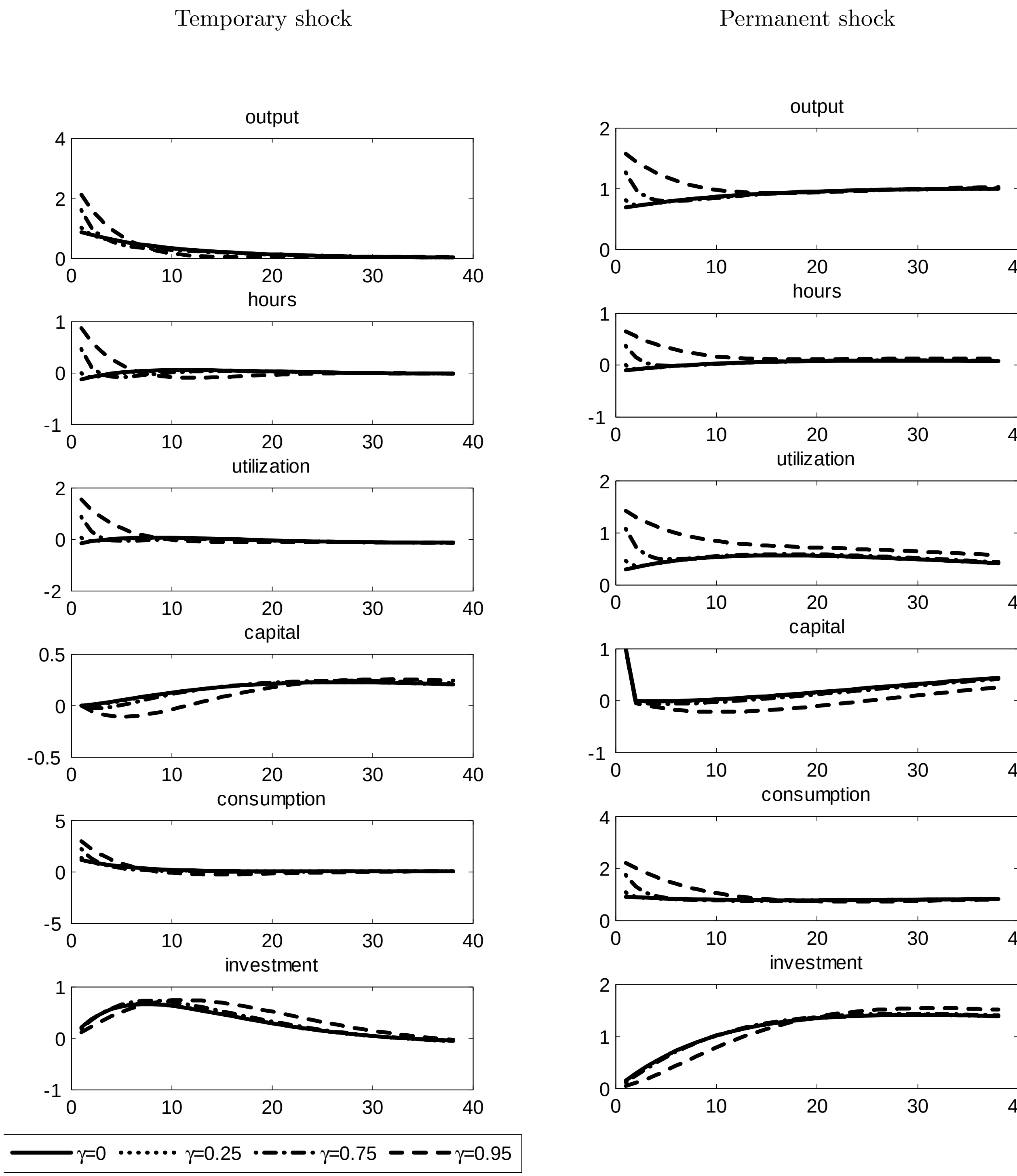

Figure 3. Impulse responses of RBC model with investment adjustment costs and varying γ.