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Quarterly Review

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Time to Plan and Aggregate Fluctuations

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A major goal of macroeconomic research for the past three decades has been the integration of macroeconomics and microeconomics. Work aiming to reach that goal has taken two related paths. One type of work has tried to give theoretical macroeconomic models firmer microeconomic foundations. The other has tried to use microeconomic data sets to construct and parameterize macroeconomic models. An example of this second type is Kydland and Prescott's (1982) classic *Econometrica* article, "Time to Build and Aggregate Fluctuations." In that article, Kydland and Prescott specify the investment gestation lags in a macroeconomic model based on published studies of major investment projects.¹

According to these studies, investment projects have two noteworthy features. One is that they usually require more time to complete than the quarterly time period in a typical macroeconomic model. This *time-to-build* feature of investment projects is emphasized by Kydland and Prescott (1982). The other noteworthy feature of investment projects is that they typically begin with a lengthy *planning phase*, during which architectural plans are drawn up, financing is arranged, permits are obtained from various local authorities, and so on.² While these are important activities that can involve some high-priced talent, the actual resource cost of this phase is small in relation to the overall cost of investment projects. The really resource-intensive phase, when physical construction actually occurs, begins later. The planning phase is typically quite long. Of the total time from a project's conception to its comple-

tion, on average, about a third is spent in the low resource use planning phase.³

Our investigation of these features of investment projects reveals that they have substantial business cycle implications. But it is the planning phase that is particularly important. The fact that investment projects take time per se has relatively modest implications for business cycle dynamics. That is documented by Kydland and Prescott (1982). They compare a model that has a four-quarter

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¹There are other examples of this type of research. Microeconomic evidence on the heterogeneous earning experiences of different households has been used to restrict macroeconomic models with limited insurance and idiosyncratic income uncertainty. Microeconomic studies of the degree of risk aversion of households, their labor supply elasticities, and their activities in the home have been used to restrict the parameters of utility functions in macroeconomic models.

²Our analysis is based on a review of the principal source cited by Kydland and Prescott 1982—Mayer 1960—as well as of Krainer 1968. These articles analyze the results of questionnaires about major capital projects undertaken by industrial firms. Complementary evidence on the planning period for investment projects appears in a study by Jorgenson and Stephenson (1967). They examine time series data on gross investment for 15 industries and find (1967, p.17) that "investment expenditure lags behind its determinants by six to 12 quarters . . . on the average."

³For example, Krainer (1968) finds that expenditures on major investment projects exhibit the classic S-curve shape, with very low expenditures initially. He studies 25 projects, mostly 1–2 years in duration. In all these projects, in the first three months, less than 5 percent of the total project cost was incurred. In 18 of them, that portion was actually less than 2.5 percent. Krainer's results understate the length of the planning period because he dates the conception of a project with its approval by a company's board of directors. Presumably, much planning has already been done for a project before that point. Mayer (1960) dates the start of a project by the first drawing up of plans. In Mayer's (1960) data, on average, projects took 22 months, with the first 7 months being the preconstruction planning phase.

time-to-build technology but no planning period (in which the investment costs are spread evenly across the four quarters) with a model that has a one-quarter time-to-build technology. They report that, for the most part, the business cycle implications of these two specifications are very similar.⁴

Overview

We will show that the planning phase of business investment helps account for at least three key features of business cycles: their persistence, the fact that productivity leads hours worked over the business cycle, and the fact that business investment in structures and business investment in equipment lag output over the business cycle.

Persistence

The *persistence* of business cycles refers to the fact that when the growth of output is above average, it tends to remain high for a few quarters, and when it is below average, it tends to remain low. A statistic for measuring persistence of output is the first-order autocorrelation of the growth of gross domestic product (GDP), that is, the correlation of GDP growth in one quarter with its growth in the preceding quarter. That autocorrelation in postwar U.S. data is 0.37.

The only way standard real business cycle models can account for this degree of persistence is by assuming persistence in the growth rate of the disturbances, or *shocks*, that drive the business cycle. For example, Christiano (1988) documents that the first-order autocorrelation of equilibrium GDP growth in a standard model (with one-period time to build) corresponds roughly to the autocorrelation of the growth rate of the exogenous shock to the level of technology. The fact that standard models require persistent shocks to account for persistence in output is said to reflect the fact that the models are missing some important internal propagation mechanisms (Rouwenhorst 1991, Watson 1993, Rotemberg and Woodford 1994, and Cogley and Nason 1995).

Enhancing internal propagation in models requires incorporating real-world features that have the effect of delaying the response of factors of production to the primary underlying shocks. We argue that, depending on the exact source of the shocks, the investment planning period can be such a feature.⁵ The need for a time-intensive, but low resource-using, planning phase at the start of new investment projects implies that the flow of resources into investment cannot be quickly changed, regardless of the type of shock. For shocks that are transmitted to factors of pro-

duction primarily by changes in investment, the delay in the response of investment translates into a delay in the response of factors of production. The *technology shock* in standard real business cycle models is such a disturbance. In this type of model, there is no planning period and hours worked responds positively to a positive technology shock. An important motivation underlying this work response is households' incentive to accumulate the investable resources they need to exploit the high rate of return on investment associated with a positive technology shock. By eliminating this incentive, incorporating a planning period into a standard real business cycle model has the effect of delaying the hours-worked response to a technology shock.

Incorporating the planning period does not have the effect of delaying the response of factors of production to every kind of shock. For example, if *shocks to government consumption* are temporary, the optimal response to such a shock in a standard real business cycle model is to let investment drop in order to absorb the rise in government consumption. This drop in effect allows households to insulate the response of hours worked and consumption from the shock. But when there is a planning period, investment cannot play this role, so hours worked must rise substantially in the period of the shock to avoid a substantial crowding out of consumption. Thus, for this kind of shock, incorporating the planning period into the model actually enhances the response of hours worked.⁶

In our analysis, we use variants of the Christiano and Eichenbaum (1992) model, which includes both technology and government consumption shocks. In that model,

⁴The primary effect of time to build in Kydland and Prescott's (1982) model is to make the capital stock lag output over the cycle, so that its correlation with output turns negative. Rouwenhorst (1991) also argues that the business cycle implications of Kydland and Prescott's time-to-build specification are not substantial.

⁵Other features have been analyzed too. For example, search models of the labor market emphasize the time-intensive nature of finding and changing employment. For that type of study, see Mortensen 1992; Andolfatto 1993; Ljungqvist and Sargent 1995; and Merz, forthcoming. Financial market frictions explored by Fuerst (1992), Fisher (1994a), and Christiano and Eichenbaum (1995) also have the effect of delaying the response of factors of production to shocks. Other discussions of the implications for persistence of limitations on the ability of labor and capital to respond to shocks are investigated by Burnside, Eichenbaum, and Rebelo (1993); Burnside and Eichenbaum (1994); Boldrin, Christiano, and Fisher (1995); and Christiano and Fisher (1995).

⁶Though we have not explored this formally, this reasoning suggests that we would see a different result for government consumption shocks which are even more persistent than in our model. Then households would have a motive to actually build up capital in the period of the shock. Using the same reasoning used to understand the impact of the planning period with the technology shock, we conjecture that the effect of the planning period with highly persistent government consumption shocks would be to delay the response of hours worked.

the technology shock is the primary disturbance driving the business cycle. Therefore, incorporating the investment planning period into this model enhances persistence.

We discover that the amount of persistence introduced by the planning period is actually quite substantial. To establish a benchmark, we first consider the conventional time-to-build specification of constant resource use over four periods. We find that, in this case, when the growth rate of the exogenous technology shock has no first-order autocorrelation, neither does equilibrium output growth. We then adapt this specification to accommodate a planning period by assuming that essentially no resources are used in the first period of a project, while a constant flow of resources is required in the remaining three periods. As before, we specify that the exogenous technology shock displays no autocorrelation in its growth rate. However, unlike before, equilibrium output growth now displays positive autocorrelation. Indeed, the model's first-order autocorrelation is 0.36, virtually the value observed in the data.

Productivity and Hours Worked

We also show that the planning period helps account for the fact that output per hour worked (*productivity*) leads hours worked over the business cycle. The reason it does has to do with the impact of the planning period on the dynamic effects of the technology shock. As discussed above, initially hours worked does not rise after a positive technology shock because agents are awaiting the completion of the planning phase of investment projects conceived in the period of the shock. Because of the damped response of hours worked, productivity rises substantially in the period of the shock. Later, after the planning phase of new investment projects is complete, hours worked surges. This pattern of response to a technology shock—first productivity rises a lot; then hours worked rises—accounts for the model's prediction that productivity leads hours worked over the cycle.

Business Investment in Structures and Equipment

As noted above, the planning period has the effect of delaying the response of investment to shocks. Thus, after a positive technology shock, output rises immediately, but investment rises only with a delay. This is why the model predicts that investment lags output over the business cycle. This implication is consistent with an important feature of the data, namely, that business investment in structures and business investment in equipment lag aggregate output (Kydland and Prescott 1990, Greenwood and

Hercowitz 1991, Fisher 1994b). Presumably, business investment in structures is the category of investment for which the planning period is most directly relevant. The planning period may also have an indirect effect on investment in equipment via the complementarity of structures and equipment.

The Models . . .

In our analysis, we use three types of models.

For comparison, we analyze a standard real business cycle model which abstracts altogether from gestation considerations in investment, by specifying that the completion of an investment project requires just one period. The specific model we use for comparison is the model with technology and government consumption shocks studied by Christiano and Eichenbaum (1992, their divisible labor model). We call this the *one-period time-to-build model*.

We also consider a version of this model, modified to incorporate a standard four-period time-to-build investment technology like the one proposed by Kydland and Prescott (1982). This technology assumes that, to complete an investment project, a constant flow of resources is required over the life of the project. We call this simply the *time-to-build model*. By comparing the implications of these two models, we can assess the business cycle consequences of time-to-build considerations per se, abstracting from investment planning considerations.

To quantify the business cycle impact of the planning phase of investment projects, we consider as well a specification in which essentially no resources are used in the period an investment project is initiated, while the remaining three periods require a uniform flow of resources. We refer to this as the *time-to-plan model*.

In all models considered, competitive allocations coincide with the choices of a fictitious benevolent planner. At time period t , that agent selects contingent plans for aggregate consumption (C_t), the number of hours for households to work in the market (n_t), and the beginning of period $t + 1$ capital stock (K_{t+1}) in order to maximize

$$(1) \quad \sum_{t=0}^{\infty} (1.03^{-0.25})^t \{ [\log(C_t)/3.92] + \log(1,369 - n_t) \}$$

where $1.03^{-0.25}$ is the discount factor; 1,369 is the endowment of usable hours per period; and 3.92 is a consumption/leisure weight. Aggregate consumption is related to private and government consumption as follows:

$$(2) \quad C_t = C_t^p + \psi G_t$$

where C_t^p denotes private consumption and the parameter ψ controls how government consumption, G_t , influences the marginal utility of private consumption. A positive value for ψ implies that an increase in government consumption reduces the marginal utility of private consumption, as when they are substitutes, and a negative value implies the opposite, as when they are complements.

We confine our analysis to two cases: $\psi = 1$ and $\psi = 0$. When $\psi = 1$ in our models, private consumption and government consumption are perfect substitutes; shocks to government consumption are perfectly offset by one-for-one adjustments in private consumption. Thus, we can say that when $\psi = 1$ in our models, government consumption shocks do not matter. This is not true, however, when $\psi = 0$. In that sort of model, private consumption and government consumption are neither substitutes nor complements, so shocks to government consumption will affect other variables. Thus, we can say that when $\psi = 0$ in our models, government consumption shocks do matter. For short, we will refer to these two versions of our models as the versions when government does or does not matter.

The resource constraint in our models is

$$(3) \quad C_t^p + G_t + I_t = K_t^{0.344} (z_t n_t)^{0.656}$$

where I_t is gross investment, output is a Cobb-Douglas function of capital and hours worked, and the variable z_t summarizes the level of technology. The logarithm of z_t evolves as a random walk, so that z_t itself is represented as

$$(4) \quad z_t = z_{t-1} \exp(\lambda_t).$$

Here λ_t is a shock to the level of technology that is independently and identically distributed as a normal distribution with mean 0.004 and standard deviation 0.018. Also, we adopt the specification

$$(5) \quad \bar{g}_t = (1 - 0.96) \log(190.8) + 0.96 \bar{g}_{t-1} + \mu_t$$

where $\bar{g}_t = \log(G_t/z_t)$ and μ_t is a shock to the level of government consumption that is independently and identically distributed as a normal distribution with mean 0 and standard deviation 0.021.

To complete our model description, we describe the technology for converting investment goods into increases in the capital stock. In the one-period time-to-build model, that technology is

$$(6) \quad K_{t+1} = (1 - 0.021)K_t + I_t$$

where 0.021 is the per-period rate of depreciation in capital. The other two models incorporate versions of Kydland and Prescott's (1982) general four-period time-to-build investment technology. That is, in the time-to-build and time-to-plan models,

$$(7) \quad I_t = \omega_1 S_{1t} + \omega_2 S_{2t} + \omega_3 S_{3t} + \omega_4 S_{4t}$$

where S_{jt} is the volume of projects j periods away from completion at the beginning of period t and ω_j is the resource cost associated with work on a project j periods away from completion, for $j = 1, 2, 3, 4$. Investment projects progress according to $S_{j,t+1} = S_{j+1,t}$ for $j = 1, 2, 3$; and starts during period t are represented by S_{4t} . The capital stock thus evolves according to

$$(8) \quad K_{t+1} = (1 - 0.021)K_t + S_{1t}$$

where S_{1t} is the volume of projects that will be completed during period t .

The standard formulation of this investment technology chooses investment weights which sum to unity and which imply that the resource costs of an investment project are distributed evenly throughout the four periods of the project. (That is, $\omega_j = 0.25$, for $j = 1, 2, 3, 4$.) This is our time-to-build parameterization.

To capture the planning feature of investment projects, we consider $\omega_1 = 0.01$ and $\omega_j = 0.33$, for $j = 2, 3, 4$. This is our time-to-plan parameterization.⁷

The three types of models are summarized in Table 1. For a discussion of the empirical basis for the parameter values we use, see Christiano and Eichenbaum 1992. From

⁷Our specifications are not consistent with the results of Mayer (1960) and Krainer (1968) in two respects. One is that the investment projects they study have a duration of approximately two years. We nevertheless adopt the one-year specification in order to preserve comparability with the existing literature and in order to capture the mix between major and minor investment projects. The other inconsistency is that resource costs at the end of the investment projects studied by Krainer tend to be relatively low. One interpretation of this is that ω_4 is low. We adopt (implicitly) an alternative interpretation, that investment projects are already producing during this phase.

As noted by McGrattan (1989), a potentially useful source for data on time-to-build weights is the U.S. Department of Commerce's "Construction Reports." These report the proportion of total cost put into place in each month of building projects of various sizes. Unfortunately, these reports contain little evidence on the magnitude of ω_1 , since they refer only to work done after physical construction begins. As we have noted elsewhere, in the sample of projects studied by Mayer (1960), construction did not typically begin until one-third of the total time devoted to an investment project had elapsed.

Table 1
The Models

Type of Model*	Description
One-Period Time-to-Build	Standard real business cycle model
Time-to-Build	Even distribution of resource costs across four periods: $\omega_1 = \omega_2 = \omega_3 = \omega_4 = 0.25$
Time-to-Plan	Few resource costs in first of four periods: $\omega_1 = 0.01, \omega_2 = \omega_3 = \omega_4 = 0.33$

*For each of the three types of models, when $\psi = 0$, government consumption shocks matter, and when $\psi = 1$, they do not.

here on, we shall be concerned primarily with describing the properties of the version of the time-to-plan model in which government matters. Other models and versions are presented solely for comparison with that model.

... And How They Work

To gain insight into how the models work, we begin our analysis by studying the dynamic responses of model variables to shocks to technology and government consumption. These responses are known as *impulse response functions*. We examine these responses only in the versions of the models in which government matters.

Technology Shocks

Charts 1–6 depict, for each model, the responses to a positive 1 percent shock to the level of technology that occurs in period 1.⁸ Because of the random walk specification, the shock has a permanent impact on the level of technology in all three models. The variables are expressed as a percentage of their values on a nonstochastic steady-state growth path. Each model has the property that eventually all variables but hours worked rise by roughly 1 percent. Hours worked eventually returns to its original pre-shock value. In all three models, hours worked and investment converge to their steady-state values from above (Charts 5 and 3), and the other variables converge from below.

There are three other notable features of these impulse responses. One is that the responses of the one-period time-to-build model and the time-to-build model are similar; in

both models, investment and hours worked surge immediately in the period of the shock, as households direct resources toward exploiting the permanent jump in the level of technology (Charts 3 and 5). Another notable feature of the impulse responses is that the responses in the time-to-plan model resemble those in the other models in the period after the shock, but not in the period of the shock. This is because, recall, in the time-to-plan model, there is relatively little to do in the period of the shock, since starting up investment projects requires first passing through a low resource use planning phase. Thus, much of the increased output generated by the technology shock is simply consumed (Chart 2), hours worked actually falls a little (Chart 5), and investment shows hardly any response (Chart 3). A third notable feature of the impulse responses is the obvious sawtooth pattern in the time-to-build and time-to-plan model responses which is not in those of the one-period time-to-build model (Rouwenhorst 1991).

To gain insight into the reasons for the sawtooth patterns, consider Chart 7, which displays the dynamic response of starts, S_{4t} , to the technology shock. The time-to-build model exhibits a four-period cycle: high, low, low, low. The time-to-plan model exhibits a three-period cycle: high, low, low. These patterns can be understood as reflecting efforts to concentrate investment activities in periods when resources are in relative abundance. For example, a straightforward way to drive the stock of capital to a higher steady state after a shock to technology is to implement a step-function pattern in investment, with a monotone declining sequence of steps, so that investment converges to the new steady state from above. This policy can be implemented by a declining sequence of jumps in starts in periods 1, 5, 9, and so on, leaving starts unchanged in the other periods. Though such a policy is undoubtedly feasible, Chart 7 indicates that it is not optimal in either model. Relative to this feasible policy, the optimal policy reschedules some starts from periods 1, 5, 9, and so on, to the other periods. For example, in the time-to-build model, shifting starts from period 1 to period 2 in effect shifts consumption from period 5, when resources are relatively abundant because new capital is just coming on line and the pace of investment is reduced, to period 1, when resources are relatively scarce.

Note in Chart 7 that the pattern of starts is different in

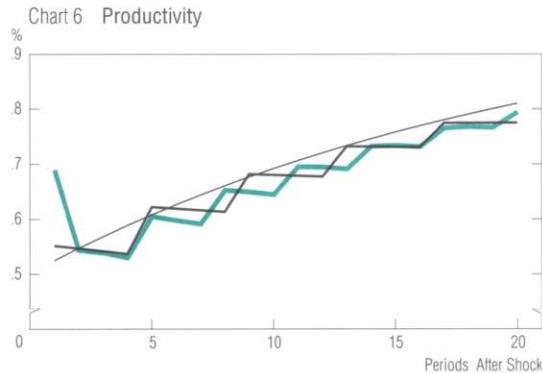
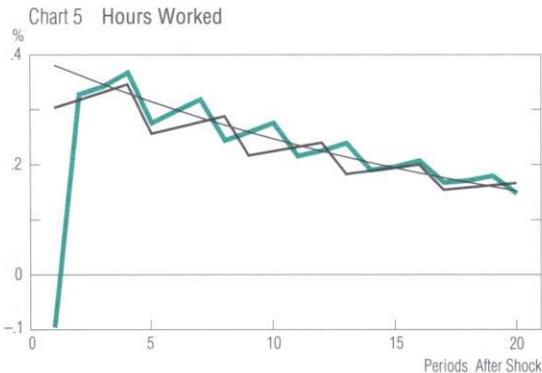
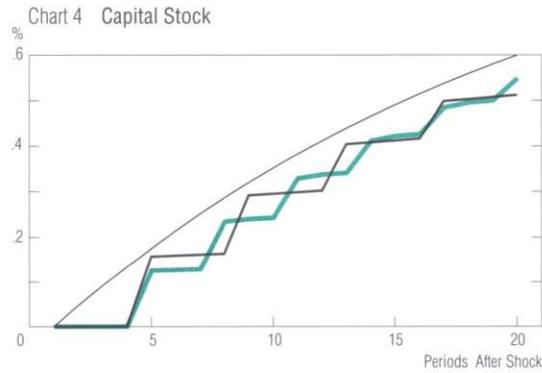
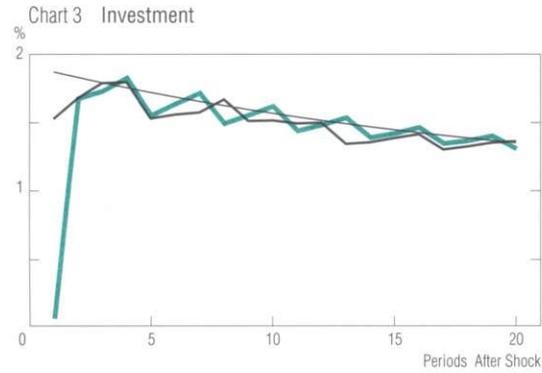
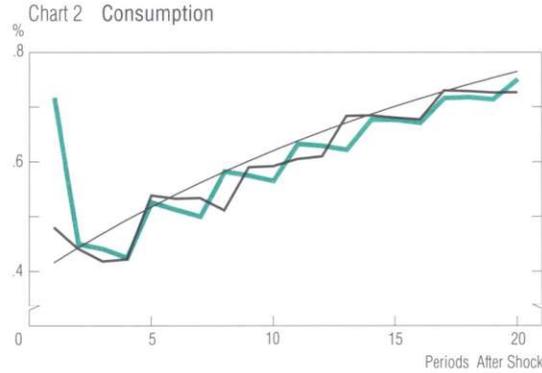
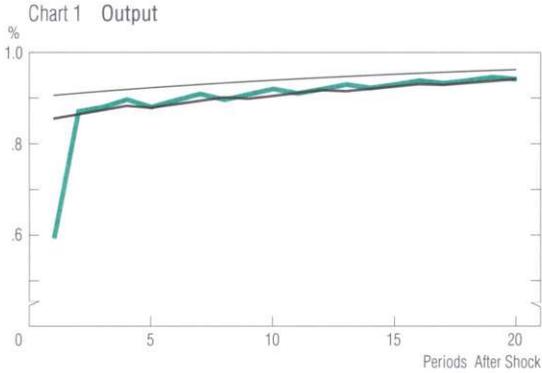
⁸That is, in all periods except the period of the shock, we set λ to its mean of 0.004. In the period of the shock, we set $\lambda = 0.014$.

Charts 1–6

Responses to a Technology Shock

Percentage Deviations From Unshocked Steady-State Paths
 After a 1 Percent Unexpected Increase in the Level of Technology in Period 1

Model:* — One-Period Time-to-Build — Time-to-Build — Time-to-Plan

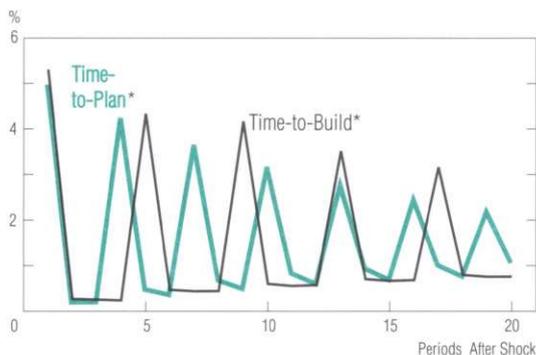


* These are the versions of the models in which government matters; that is, in equation (2), $\psi = 0$. In these models, therefore, total consumption and private consumption are identical.

Chart 7

Response of Starts to a Technology Shock

Percentage Deviations From Unshocked Steady-State Paths After a 1 Percent Unexpected Increase in the Level of Technology in Period 1



* In both models, government matters; in equation (2), $\psi = 0$.

the two models. In the time-to-plan model, this impulse response function has a three-period cycle. Presumably, the reason the four-period cycle in the time-to-build model is no longer optimal is that a surge in starts in period 4 does not represent a tax on resources until period 5, when resources are relatively abundant for the reasons given above. The projects started in period 4 will, in turn, come on-line in period 8, which helps stimulate another surge of starts in period 7, and so on.

The sawtooth pattern in the quantity responses in Charts 1–6 reflects the pattern of starts. For example, the fact that starts are always positive is the reason investment rises throughout most of the cycles displayed in Chart 3. In addition, each upward trend in hours worked (Chart 5) reflects a similar trend in aggregate investment, with the initial large increase in starts followed by smaller increases. Conditional on the pattern of investment, one can think of the work decisions as solving a sequence of static problems (as in Aiyagari, Christiano, and Eichenbaum 1992). With after-investment resources reduced in these static problems, and with leisure being a normal good, the consumption of leisure falls.

Government Consumption Shocks

Charts 8–13 depict, for each model, the responses to a positive 1 percent shock to the level of government consump-

tion that occurs in period 1.⁹ Our specification guarantees that this shock has only a temporary impact on government consumption and, hence, on all other variables in the model.

Here, as with technology shocks, the impulse responses of the one-period time-to-build model and the time-to-build model are qualitatively very similar. In both models, the response to the government consumption shock is to raise hours worked (Chart 12) and reduce consumption and investment by a small amount (Charts 9 and 10).¹⁰ However, the planning period assumption has a different impact on the propagation of government consumption shocks than on technology shocks. With both, it has the effect of inhibiting the response of investment to the shock. But this now has the effect of magnifying the impact on hours worked and output. Since the amount of resources absorbed by investment is almost completely determined at the time of a shock, the consumption/leisure problem in the period of the shock is the solution to a static problem in which investment plays the role of an exogenous tax, and the increase in government consumption operates like an exogenous drop in income. The assumption that leisure is a normal good, implicit in our specification of utility, then guarantees that hours worked must rise sharply.

Results

Our objective is to investigate the business cycle implications of key features of investment gestation lags. To do this, we need a quantitative characterization of business cycles. The characterization we adopt is a specific set of correlations and standard deviations computed using detrended data. For ease of comparability, the set of statistics and the detrending method we adopt include the conventional ones used in the business cycle literature. For convenience, we here report the business cycle statistics for postwar U.S. data. We then go on to report the corresponding statistics for our models.

The U.S. Data

Table 2 reports key business cycle statistics for the U.S. economy. Since these have been analyzed elsewhere (in Kydland and Prescott 1990, for example), they need not

⁹In all periods except the period of the shock, we set μ to its mean of 0. In the period of the shock, we set $\mu = 0.01$.

¹⁰Recall equation (2): consumption $C_t = C_t^p + \psi G_t$, where C_t^p is private consumption and G_t government consumption. However, since $\psi = 0$ in the models used in Charts 1–13, $C_t = C_t^p$ in them; that is, total consumption and private consumption are identical.

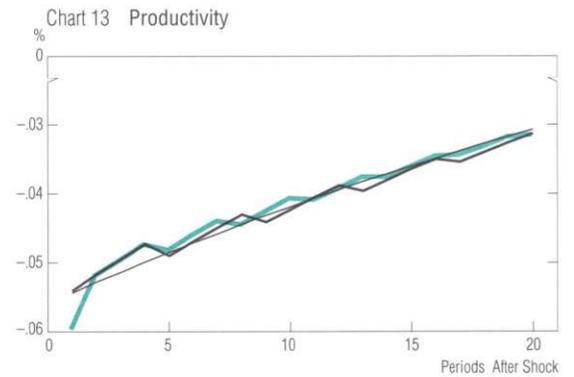
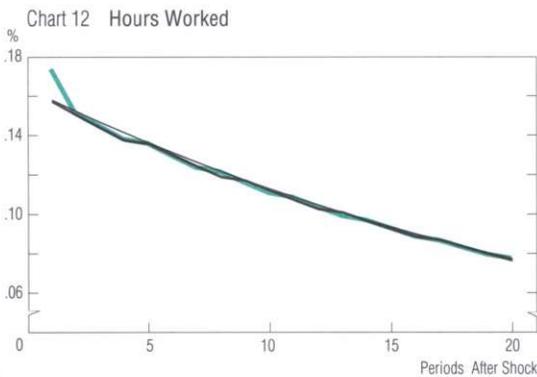
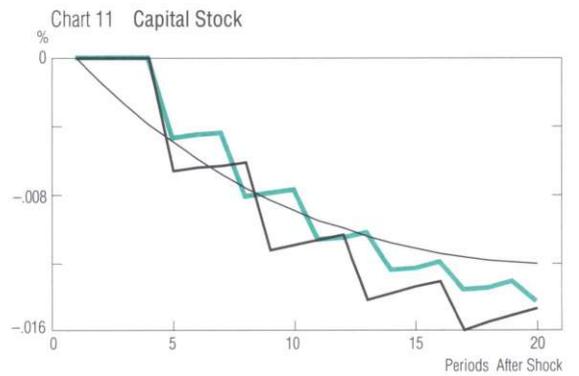
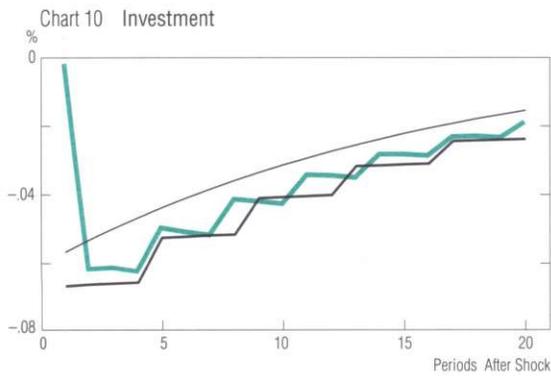
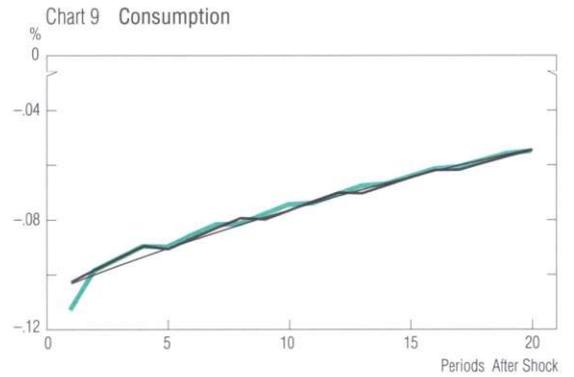
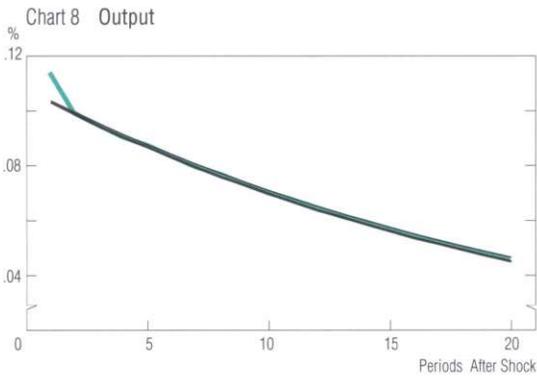
Charts 8–13

Responses to a Government Consumption Shock

Percentage Deviations From Unshocked Steady-State Paths

After a 1 Percent Unexpected Increase in the Level of Government Consumption in Period 1

Model:* — One-Period Time-to-Build — Time-to-Build — Time-to-Plan



*In all three models, government matters; in equation (2), $\psi = 0$. In these models, therefore, total consumption and private consumption are identical.

be discussed in detail here. Still, we want to emphasize three sets of facts.

First, the bottom row of Table 2 displays the autocorrelation of U.S. GDP growth. Note that the lag 1 autocorrelation is 0.37, with a small standard error of 0.07. The lag 2 autocorrelation is also significantly above zero, but the next-higher autocorrelation is not significantly different from zero. These statistics measure the persistence in aggregate output.

Second, in the dynamic cross-correlation between hours and productivity, the contemporaneous correlation is nearly zero, while the correlation between productivity and future hours is positive and quite significant.

Third, aggregate investment is contemporaneous with the cycle. However, this fairly simple cyclical pattern actually disguises more heterogeneous cyclical behavior at the disaggregated level. To see this, look again at Table 2. There we also report results for two subcomponents of investment: structures and durable goods. These two are further disaggregated, with structures divided into business and residential and durables divided into business equipment and household durables.

Two notable features emerge here. One is that business investment in structures and business investment in equipment lag the business cycle. In light of the evidence presented in Mayer 1960 and Krainer 1968, we think these data can reasonably be interpreted as reflecting investment planning delays. We suspect that the planning period necessary for equipment investment is shorter than that for structures. Still, to the extent that there are complementarities between structures and equipment, we would expect planning delays in structures investment to induce some delays in equipment investment too. Another feature worth noting is that residential investment in structures and investment in household durables both lead the business cycle. This feature suggests that significant planning periods may not be required for these types of investment.

The size of the standard errors for all these types of investment suggests that there is considerable sampling uncertainty in the data, so caution is warranted in making inferences about their cyclical properties.

The Model Statistics

Table 3 presents the results for our models. The entries in the table are selected with the objective of shedding light on the role played by time to build, time to plan, and government consumption shocks. That is, the four sets of statistics in the table isolate the effects of adding, one by

one, multiperiod time to build, time to plan, and government consumption to a baseline one-period time-to-build model in which government does not matter.

Consider the results for that baseline model. A detailed discussion of its business cycle implications appears in Christiano and Eichenbaum 1992. Notable among these are the model's success in accounting for the observed relative smoothness of consumption (private plus government) and its failure in accounting for the observed low volatility of productivity relative to hours worked (Hansen 1985). Here we want to point out three other things. First, there is essentially no persistence in aggregate output; output growth displays basically zero autocorrelation at lags 1, 2, and 3. Second, hours worked is contemporaneous with productivity over the cycle, in the sense that the maximal value in their dynamic correlation appears at lag zero. And finally, investment neither leads nor lags output over the cycle.

Now consider what happens when we introduce time-to-build considerations alone, abstracting from planning considerations and from government consumption shocks. There are at least two things to note here. First, the dynamics of consumption are substantially altered: the relative volatility of consumption is quite high, and the contemporaneous correlation of consumption with output is low. Second, the volatility of productivity in relation to hours worked is higher than before. Intuition for these results may be obtained by studying the impulse response functions in Charts 1–6.¹¹ There, in the time-to-build model compared to in the one-period time-to-build model, consumption responds more to a shock (Chart 2), hours worked responds less (Chart 5), and, hence, productivity responds more (Chart 6). Thus, the small changes introduced by time to build actually hurt the model's ability to account for business cycles.

Now consider the results for the time-to-plan model in which government doesn't matter. Note that the degree of persistence has increased substantially, even overshooting the corresponding empirical quantity somewhat, at least at lag 1. Also, productivity now leads hours worked over the cycle. Interestingly, the impact on the contemporaneous correlation between hours and productivity is quite substantial; that correlation drops from roughly 0.90 in the

¹¹Recall that the responses in these charts are for the versions of the models in which government matters. However, the basic shapes are similar for responses from the versions in which government doesn't matter.

Table 2
Selected U.S. Business Cycle Statistics
Quarterly, 1947:1–1995:1,* Seasonally Adjusted

Variables†		Relative Volatility σ_B / σ_A	Dynamic Correlations of $A(t)$ With $B(t-j)$, Where $j =$						
<i>A</i>	<i>B</i>		3	2	1	0	-1	-2	-3
Output, <i>Y</i>	—	.0179**	.40 (.08)	.65 (.07)	.86 (.04)	1.00 (.00)	.86 (.04)	.65 (.06)	.40 (.08)
Output, <i>Y</i>	Consumption, <i>C</i>	.46 (.03)	.42 (.09)	.61 (.08)	.76 (.06)	.78 (.05)	.66 (.06)	.48 (.08)	.30 (.09)
<i>Y</i>	Investment, <i>I</i>	2.91 (.22)	.43 (.09)	.57 (.09)	.68 (.08)	.71 (.09)	.56 (.11)	.33 (.13)	.08 (.15)
	<i>Structures</i>								
<i>Y</i>	Business	2.67 (.28)	-.16 (.10)	.03 (.10)	.25 (.09)	.46 (.08)	.56 (.08)	.59 (.09)	.53 (.10)
<i>Y</i>	Residential	6.04 (.52)	.57 (.10)	.63 (.09)	.61 (.10)	.49 (.11)	.26 (.13)	.00 (.14)	-.21 (.13)
	<i>Durable Goods</i>								
<i>Y</i>	Business Equipment	3.43 (.20)	.16 (.09)	.38 (.08)	.62 (.06)	.80 (.04)	.81 (.05)	.68 (.07)	.48 (.09)
<i>Y</i>	Household Durables	3.04 (.29)	.44 (.11)	.48 (.12)	.51 (.12)	.49 (.13)	.30 (.14)	.09 (.14)	-.15 (.15)
<i>Y</i>	Government Consumption, <i>G</i>	2.14 (.37)	-.01 (.14)	.10 (.12)	.21 (.11)	.34 (.11)	.43 (.12)	.47 (.13)	.48 (.13)
<i>Y</i>	Hours Worked, <i>n</i>	.82 (.06)	.18 (.09)	.41 (.08)	.66 (.05)	.82 (.03)	.81 (.05)	.69 (.07)	.52 (.09)
<i>Y</i>	Productivity, <i>Y/n</i>	.58 (.05)	.42 (.10)	.53 (.09)	.55 (.08)	.55 (.09)	.32 (.11)	.12 (.12)	-.06 (.12)
Hours Worked, <i>n</i>	Productivity, <i>Y/n</i>	.70 (.08)	.35 (.09)	.33 (.09)	.21 (.10)	-.03 (.11)	-.07 (.12)	-.17 (.11)	-.24 (.09)
Output Growth, ΔY	—	.0099**	.03 (.08)	.22 (.08)	.37 (.07)	1.00 (.00)	.37 (.07)	.22 (.08)	.03 (.08)

* Hours-worked data are for 1947:1–1993:4.

** These numbers are simple, not relative, standard deviations.

† Variable definitions and Citibase codes are as follows: *Y* = Gross domestic product = GDPQ; *C* = Consumption of nondurable goods and services = GCNQ + GCSQ; *I* = Business fixed investment + Consumption of durable goods = GIFQ + GCDQ; Business investment in structures = GISQ; Residential investment = GIRQ; Business equipment investment = GIPDQ; Household investment in durable goods = GCDQ; *G* = Government consumption = GGEG; *n* = Hours worked by employed labor force = LHOURLS; ΔY = The first difference of the log of per capita gross domestic product. Note that the measure of *C* places a weight of zero on government consumption.

All variables except output growth have been logged and detrended with the Hodrick-Prescott filter. All variables have been divided by GPOP, a non-seasonally-adjusted measure of population (including armed forces overseas) and are measured in 1987 dollar terms.

Numbers in parentheses are standard errors computed as in Christiano and Eichenbaum 1992. For estimation of the relevant zero-frequency spectral density, a Bartlett window, truncated at lag 4, was used.

Source: Citicorp's Citibase data bank

Table 3
Selected Model Statistics*

Model	Variables		Relative Volatility σ_B / σ_A	Dynamic Correlations of $A(t)$ With $B(t-j)$, Where $j =$							
	<i>A</i>	<i>B</i>		3	2	1	0	-1	-2	-3	
Government Doesn't Matter	One-Period Time-to-Build	<i>Y</i>	—	.021**	.31	.51	.74	1.00	.75	.51	.31
		<i>Y</i>	<i>C</i>	.55	.23	.44	.69	.98	.78	.59	.41
		<i>Y</i>	<i>I</i>	2.37	.36	.55	.76	.99	.70	.45	.24
		<i>Y</i>	<i>n</i>	.38	.39	.57	.77	.98	.67	.40	.18
		<i>Y</i>	<i>Y/n</i>	.63	.26	.47	.71	.99	.78	.57	.39
		<i>n</i>	<i>Y/n</i>	1.65	.11	.33	.61	.94	.77	.61	.45
		ΔY	—	.016**	.01	.03	.04	1.00	.04	.03	.01
	Time-to-Build	<i>Y</i>	—	.018**	.25	.45	.70	1.00	.70	.45	.25
		<i>Y</i>	<i>C</i>	.76	.03	.12	.24	.39	.26	.17	.15
		<i>Y</i>	<i>I</i>	2.26	.29	.48	.71	.98	.70	.45	.22
		<i>Y</i>	<i>n</i>	.35	.31	.49	.70	.95	.69	.43	.18
		<i>Y</i>	<i>Y/n</i>	.67	.21	.42	.67	.99	.68	.45	.28
		<i>n</i>	<i>Y/n</i>	1.91	.13	.40	.65	.89	.68	.49	.34
		ΔY	—	.014**	-.01	.00	.01	1.00	.01	.00	-.01
	Time-to-Plan	<i>Y</i>	—	.017**	.30	.53	.82	1.00	.82	.53	.30
		<i>Y</i>	<i>C</i>	.91	.13	.24	.39	.35	.05	.01	.02
		<i>Y</i>	<i>I</i>	2.48	.22	.39	.60	.87	.94	.64	.36
		<i>Y</i>	<i>n</i>	.47	.14	.25	.39	.68	.91	.62	.34
		<i>Y</i>	<i>Y/n</i>	.76	.31	.55	.83	.89	.52	.32	.19
		<i>n</i>	<i>Y/n</i>	1.63	.39	.66	.91	.28	.24	.17	.12
		ΔY	—	.011**	.01	.01	.40	1.00	.40	.01	.01
Government Matters	Time-to-Plan	<i>Y</i>	—	.018**	.30	.53	.81	1.00	.81	.53	.30
		<i>Y</i>	<i>C</i>	.67	.26	.46	.70	.70	.29	.16	.10
		<i>Y</i>	<i>I</i>	2.21	.21	.38	.59	.84	.93	.63	.36
		<i>Y</i>	<i>G</i>	2.00	.24	.41	.61	.72	.50	.32	.18
		<i>Y</i>	<i>n</i>	.54	.17	.30	.47	.74	.87	.59	.33
		<i>Y</i>	<i>Y/n</i>	.70	.30	.52	.79	.85	.49	.30	.18
		<i>n</i>	<i>Y/n</i>	1.29	.33	.56	.78	.28	.22	.15	.11
ΔY	—	.012**	.00	.01	.36	1.00	.36	.01	.00		

*Statistics are based on 2,000 artificial observations from the indicated model. For data descriptions, see notes to Table 2, except that here consumption, *C*, also includes ψG , where *G* is government consumption. When government doesn't matter, $\psi = 1$, and when it does, $\psi = 0$.

**These numbers are simple, not relative, standard deviations.

other two models to 0.28 in the time-to-plan model. Qualitatively, these results were anticipated by the impulse response functions in Charts 1–6.

Other time-to-plan model implications include that investment lags output over the business cycle. Although this is not consistent with the evidence on aggregate investment, it is qualitatively consistent with the evidence on business investment in structures and equipment. Time to plan also has two important impacts on the dynamics of consumption. First, consumption now leads the cycle. The reason for this is clear from the impulse response functions in Charts 1 and 2: Consumption surges in the period of the shock, while the impact on output is delayed. This implication of the model is counterfactual. Second, model performance deteriorates noticeably with respect to the relative volatility of consumption and its correlation with output. This also reflects the very strong response of consumption in the period of the shock.

Finally, we can assess the effects of letting government consumption shocks matter in the time-to-plan model. There are at least four things worth emphasizing about switching to this version of the model.

First, the incorporation of government consumption shocks actually reduces the degree of persistence in output. This is not surprising in view of the previous analysis, which shows that time to plan enhances the response of hours worked to a relatively transient government consumption shock. By reducing the model's implied first-order autocorrelation of consumption to 0.36, government consumption shocks bring the model into rough conformity with the corresponding empirical estimate.

Second, the introduction of government consumption shocks does not alter the model's implication that productivity leads hours worked. However, it does generate a marginal improvement by producing an overall reduction in the dynamic correlation between hours worked and productivity. (Christiano and Eichenbaum 1992 discusses the economics underlying this result.)

Third, the introduction of government consumption shocks reduces the relative volatility of consumption, offsetting a counterfactual implication of the model without government consumption shocks.

Fourth, government consumption shocks contribute almost nothing to output volatility. It is because technology shocks dominate in the dynamic behavior of the model that time to plan results in so much persistence in output growth.

Concluding Remarks

Studies of major investment projects suggest that these projects begin with a lengthy planning period, during which the direct expenditure of resources is relatively small. This is the time when architects draw up plans, financing is arranged, environmental impact statements are produced, permits are obtained from various local authorities, and so on. We have shown that this planning period may help account for several key features of business cycles: their persistence, the fact that productivity leads hours worked over the cycle, and the fact that business investment in structures and business investment in equipment lag output over the cycle.

To demonstrate this, we incorporated a planning period for investment into an otherwise standard real business cycle model. We did so by adopting a four-period time-to-build investment technology in which only a negligible amount of resources is used in the first period. The planning period induces a delay in the equilibrium response of hours worked, which in turn induces a delay in the response of output. The latter delayed response is responsible for the model's ability to account for the observed persistence in output. The delay in the response of hours worked, together with the fact that a technology shock immediately raises productivity, accounts for the fact that productivity leads hours worked over the business cycle.

The model also predicts that investment lags output over the business cycle and that consumption leads. These implications are counterfactual, given the level of aggregation in the model: quarterly U.S. aggregate consumption and investment appear to be contemporaneous with the cycle. However, we believe these shortcomings of our model are not fundamental.

The cyclical behavior of aggregate investment masks considerable heterogeneity in the cyclical properties of the components of investment. In particular, business investment in structures and business investment in equipment lag output over the business cycle, while residential investment and household durables lead. We suspect that a model which distinguishes among these categories of investment, assumes a significant planning period for business structures investment only, and specifies that structures and equipment are complementary can overcome some of the deficiencies of our model.

The assumption of a planning period for business investment in structures should make that form of investment lag the business cycle, and complementarity between

structures and equipment should induce a lag in equipment investment as well. At the same time, the factors that make consumption lead the cycle in our model should make residential investment and household durables lead the cycle in a modified model. In our model, the reason consumption leads output over the cycle is that consumption surges in the period of the technology shock: there is nowhere else for the extra resources to go, since investment cannot be changed in the short run. In a modified model, a major category of investment would be available for absorbing such resources, and we expect households in such a model to take advantage of it. We conjecture that in the modified model, residential investment and household durables will lead the cycle because such a model will still have a delay in the response of hours worked and, hence, output to a shock. The delay, though probably not as strong as in our model, will nevertheless be there because of the binding short-run constraint on expanding the resources devoted to business investment in structures.

In part, these comments are meant to emphasize that we view our work primarily as preliminary and, we hope, suggestive. Further analysis of quantitative models is required to fully evaluate the idea that the planning period plays an important role in propagating business cycle shocks.

Further empirical work along the lines of Mayer 1960 and Krainer 1968 is also needed. For example, it would be interesting to know to what extent firms do project planning in advance, so that when the incentive arises, they have access to an inventory of already-planned investment projects that can be implemented immediately. To the extent that this is true, the business cycle significance of the planning considerations analyzed here would be reduced.

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