1-1-1985

Capital Utilization and Capital Accumulation: Theory and Evidence

Matthew D. Shapiro

COWLES FOUNDATION FOR RESEARCH IN ECONOMICS

AT YALE UNIVERSITY

Box 2125, Yale Station
New Haven, Connecticut 06520

COWLES FOUNDATION DISCUSSION PAPER NO. 736

CAPITAL UTILIZATION AND CAPITAL ACCUMULATION

THEORY AND EVIDENCE

by

Matthew D. Shapiro

January, 1984

CAPITAL UTILIZATION AND CAPITAL ACCUMULATION:

THEORY AND EVIDENCE

Matthew D. Shapiro[1]

Cowles Foundation for Research in Economics
Yale University
Box 2125 Yale Station
New Haven, CT 06520

Revised November 1984

ABSTRACT

A firm may acquire additional capital input by purchasing new capital or by increasing the utilization of its current capital. The margin between capital accumulation and capital utilization is studied in a model of dynamic factor demand where the firm chooses capital, labor, and their rates of utilization. A direct measure of capital utilization--the work week of capital--is incorporated into the theory and estimates. The methodology advocated by Hansen and Singleton (1982) is used to obtain estimates of the model's parameters. This methodology allows the firm's decision problem to depend on expected values of future endogenous and exogenous variables without imposing strict assumptions on functional form or the distribution of shocks to the system.

The estimates imply that capital stock is costly to adjust while the work week of capital is essentially costless to adjust. Hence, the work week of capital overshoots the steady state when innovations in policy or other shocks change the demand for capital. Short run variation in the demand for capital is met by changing utilization. Long run variation is met by changing the stock. The estimated response of the capital stock to changes in its price and in the required rate of return is substantial and it takes place more quickly than found in other estimates. These results provide an important challenge to the view that input prices and required rates of return are empirically unimportant in models of the demand for capital.

1. Introduction

In this paper, I examine the link between capital utilization and the dynamic demand for capital. In the model, the firm can vary the intensity of use of its capital by lengthening its work week as well as by changing the work week and amount of labor. When a firm decides--for whatever reason--that it needs more capital services than it already has, it has two options. It may either acquire additional physical capital or use its current capital more intensively. As long as the firm is not at a corner, it has these two choices regardless of whether the quantity of labor is increased correspondingly. That is, the choice of amount of capital services can be made separately from the choice of labor input and the capital-labor ratio.

The Federal Reserve Board's and the Bureau of Economics Analysis's published measures of capacity utilization are not necessarily economically meaningful measures of capital utilization. Each measures output relative to trend rather than at what rate of intensity capital is being used. In this paper, I discuss an alternative measure of capital utilization, the work week of capital. By assuming that capital is idle if no labor is present, the work week of capital can be deduced from data on shift work of labor. I discuss construction of such a series, present some results about its statistical properties, and integrate it into a model of dynamic factor demand. I estimate the model of dynamic factor demand and study how capital accumulation and capital utilization respond to changes in the cost of capital.

The aim in this paper is to analyze and quantify how the firm's ability to vary capital utilization impinges on its demand for capital. Why firms use their capital so little is a persistent puzzle. The main purpose of this paper is not to resolve this puzzle, but rather to analyze how the margin between extending shift work and adding new capital affects the decision to buy new capital. Nonetheless, my estimates are consistent with the view that the productivity of shift work is low.[2]

Uncertainty about the future plays a central role in the firm's investment decision. For example, whether the firm expects a shock to be permanent or temporary will determine whether it responds mainly by increasing its capital stock or by increasing the utilization of the current stock. I use the research strategy advocated by Hansen and Singleton (1982) of estimating the stochastic first-order conditions of the firm's decision problem. This methodology allows expected future outcomes to drive current decisions without requiring the econometricians to characterize fully their distribution.

To simulate the estimated model, I make further assumptions about the environment facing the firm. I can then solve using the algorithm of Blanchard and Kahn (1980) for the estimated response of capital demand and capital utilization to changes in factor prices. The current response of demand and utilization depends on current and future values of factor prices and the required rates of return. These changes can arise because of changes in tax policy. Hence, the estimates can be used to study changes in tax policy based on estimated structural parameters of the representative firm's objective function.

In Section 2, I discuss the work week of capital as a measure of capacity utilization. In Section 3, I discuss the theory of interrelated factor demand with variable factor utilization. I present estimates of the model in the fourth section. In the fifth section, I consider some extensions concerning the overidentifying restrictions of the model and the aggregation problem. I explore in Section 6 the dynamic response of capital to changes in costs induced, for example, by changes in tax policy. The work week of capital overshoots the steady state when prices and rates of return change. The estimated response of capital stock to changes in prices and required rates of return is substantial. This result provides an important challenge to the standard view that prices and required rates of return are empirically unimportant in models of the demand for capital. I summarize the results in the last section.

2. Measuring Capital Utilization

There is no officially published time series directly measuring capital utilization in U.S. manufacturing. "Capacity utilization" as published by the FRB, BEA, or in the Wharton index is a measure of detrended output, not a measure of capital utilization. This point is stressed not to criticize the FRB, BEA, or Wharton indexes *per se* but to characterize their economic content. In particular, they do not well measure the intensity of use of the capital stock as maintained by some researchers (Nadiri and Rosen (1969) and Tatom (1980), for example). I discuss in the Appendix how these measures of capacity utilization are essentially detrended output. The correlation of detrended value-added in manufacturing and the FRB index is 0.88.

The measure of capital utilization I propose to use is the average work week of capital. The series is analogous to the well-known average work week of labor, H_t, measured in man-hours. Capital is working only if some labor is present, that is, if the plant is open. Published information on shift work is therefore used to construct the implied work week of capital.

The Bureau of the Census in 1929 collected and again since 1973 collects information directly on the work week of capital (see Foss (1981) for details). These data are too infrequent and not collected over a long enough continuous time span to be useful in this study.

The measure of the work week of capital I use here is based on the number of workers on late (second and third) shifts in manufacturing. Data on shift work are available beginning in the early 1950s from the Area Wage Survey conducted by the Bureau of Labor Statistics. The survey gives the percentage of workers on the second and third shifts in the various SMSAs. Let L_1 , L_2 , and L_3 denote employment on the first, second, and third shifts. Consider a series

$$S = [H(L_1 - L_2) + 80(L_2 - L_3) + 120L_3]/L_1 \quad (1)$$

The series S measures the work week of capital. Equation (1) is equivalent to Taubman and Gottschalk's (1971) equation (2.3) up to a normalization. Suppose that only one shift is worked so L_2 and L_3 are both zero. In this case S , the work week of capital, equals H , the work week of labor. Increasing the utilization of capital is achieved exactly by increasing the utilization of labor. The index is constructed so that overlapping shifts are not double-counted. In particular, it assumes that overtime work on one shift overlaps with that on another shift if more than one shift is worked. This insures that S does not overstate the length of the work week of capital. In particular, it helps to ensure that S is not spuriously correlated with the work week of labor, which is an alternative indicator of capital utilization.[3]

Now suppose that two equally-sized shifts are worked so that L_1 and L_2 are equal and L_3 is zero. Then the work week of capital is eighty hours. (No information is available on the length of late shifts so average hours are used.) If three equal shifts are worked, then the work week of capital is 120. It is presumed that if more than one shift works, they are of equal size. Therefore, L_1 , L_2 , and L_3 can be deduced from aggregate production workers, L , and from the shares of shift work in the Area Wage Survey.

Taubman and Gottschalk (1971) construct a quarterly index S for 1952 through 1968 based on Area Wage Survey data. The Survey is conducted for different SMSAs at different points in time. They use this information to construct a quarterly series from the disaggregate data. I extend the series through 1982 based on published and unpublished summary statistics for the post 1968 period.[4] I then use a modification of the Chow-Lin (1969) procedure for best linear unbiased distribution. The instrument for the distribution is quarterly average hours. I estimate the relationship between quarterly hours and S on the 1952 to 1968 period. From these estimates, I construct fitted values for quarterly S after 1968 by redistributing the annual residual equally over each quarter of the year. The entire series is given in the Appendix.

Use of an interpolated series creates an errors-in-variables problem. In Section 5.2, I discuss estimates that are robust to measurement error in S .

There are two major shortcomings to use of this measure of the work week of capital as a measure of capital utilization. First, because of data limitations, it does not account for work on weekends. In 1976, the average plant in the U.S. manufacturing industry operated 5.3 days per week (Foss (1981, p. 9)) so at least on average weekend work is negligible. Second, the measure is for capital in use so it does not account for temporary plant closings. Permanent plant closings should, in principle, be captured in the measured capital stock.

Before presenting the theoretical model of the interrelation between the stock demand and utilization of factors, it is useful to consider the correlation of the work week of capital with other macroeconomic variables. For the following discussion, I detrend the data with linear and quadratic trends.[5] The correlation of the work week of capital with output is 0.66, so it is strongly pro-cyclical. The correlation of the work week of production workers with output is 0.70; the utilization rates of capital and labor are about equally correlated with output. The two utilizations have correlation 0.77.

The correlation of the work week of capital with labor productivity (output per man-hour) is 0.13. Longer hours for capital means a higher effective capital-labor ratio, and consequently higher labor productivity. The correlation of the capital stock with the same measure of labor productivity is 0.08, so high frequency changes in productivity are more substantially correlated with the work week than the stock of capital. Foss (1981) emphasizes the importance of changes in capital utilization for the trend determination of productivity. Tatom (1980) notes that variation in capital utilization might explain pro-cyclical labor productivity. The correlations presented here are consistent with capital utilization being part of the source of pro-cyclic productivity. Tatom uses FRB capacity utilization to proxy for capital utilization, which, for reasons I discuss above, does not directly measure capital utilization.

3. Factor Utilization and the Theory of Dynamic Factor Demand

The technology I study allows the firm to choose independently its capital and labor stocks and their rates of utilization. The firm takes factor and product prices as given. The level of output is determined by the firm's choice of inputs and their utilizations rather than by an exogenous constraint. Thus, the choice of the rate of utilization determines output, and not *vice versa*. The scope to vary utilization gives the firm flexibility in responding to shock to demand and cost. In particular, it may respond to temporary shocks principally by adjusting utilization and to permanent shocks principally by adjusting the stock of a factor.

The effect of varying utilization on maximized profits can be divided into four parts. First, under typical concavity assumptions, increasing the utilization of one factor should decrease the marginal product of that factor. Second, increased factor utilization may impose added variable cost on the firm. For example, to increase labor utilization a firm must pay the wage rate plus a possible premium for overtime. To add a shift the firm may pay a shift premium. Third, as I demonstrate, changing utilization or quantities employed by different factors implies different adjustment costs. These different adjustment costs have different implications for profits. Specifically, the adjustment cost of capital is substantial and significant, that of employment is smaller yet significant, and that of hours of employees and of capital is nil. Fourth, the rate of utilization may affect user cost of capital by changing the rate of depreciation (see Taubman and Wilkinson (1970)). Making the rate of depreciation endogenous has the unfortunate consequence of making the level of the capital stock unobservable. Therefore, I do not examine the implications of utilization for user cost in the context of this paper's model.

Nadiri and Rosen (1969) study capacity utilization in a model where firms are not explicitly forward-looking. They study dynamically interrelated factor demands for labor and capital where the level of utilization of both capital and labor are choice variables of the firm. They use a Cobb-Douglas production function where capital, capacity utilization, employees, and hours of employees all have different shares. Nadiri and Rosen use capacity utilization to measure capital utilization. Measured capacity utilization is essentially output divided by trend. Consequently, capacity utilization as measured cannot be an independent choice of the firm. It is therefore misleading to estimate an independent "demand" for it.[6]

The literature on interrelated factor demand under rational expectations largely overlooks the issue of capacity utilization. That is, it is typically assumed that the current stock of factors is always utilized fully. An exception is theoretical work by Abel (1979), whose model is close to the one in this paper. Sargent (1978) estimates a dynamic demand function for labor. He does in a sense address the issue of utilization by estimating separate demands for straight-time and overtime employment. He finds that straight-time employment has a cost of adjustment far in excess (e.g., 40 times) that for overtime employment. His conclusion regarding the different cost of adjustment of overtime and straight-time work is similar to a result in this paper: that the number of employees is costly to adjust but that the number of hours they work is not. He does not, however, study demand for capital or its utilization.

In other studies of dynamic factor demand under rational expectations, factors are utilized fully. Meese (1980) estimates the interrelated demands for capital and man-hours. Kennan (1979) estimates the demand for labor as a function of current and expected future output. Pindyck and Rotemberg (1983) separate white-collar from blue-collar employment but again assume that each is utilized at a constant rate.

I now consider an explicit model of the firm that yields demands for both capital and labor and their rates of utilization.

3.1. Technology

This section extends the theory of interrelated factor demand to account explicitly for the firm's separate choice of factor utilization.[7] In addition to choosing its stock of capital, K_t, its stock of production workers, L_t, and their hours, H_t, and its stock of non-production workers, N_t, it can also choose the number of shifts it operates. The number of shifts is proportional to the work week of capital, S_t. That is, the number of shifts is essentially the ratio of S_t to H_t.

If the firm chooses to extend the work week of capital, S_t, without changing labor input, it would correspondingly reduce the effective capital-to-labor ratio. Thus, one would expect, but not require, that the firm add labor when it adds shifts. If the work week of capital is extended by lengthening the work week of production workers, H_t, then no corresponding increase in labor is required to keep fixed the ratio of workers to machines.

To make consideration of the technology concrete, consider the production function to be used in the empirical work. I use a Cobb-Douglas function augmented by terms for costs of adjustment. It is

$$(2)\quad \log y_t = \log[f(K_t, L_t, N_t, H_t, S_t, K_t - dK_{t-1}, L_t - q_{t-1}L_{t-1}, N_t - q_{t-1}N_{t-1}, H_t - H_{t-1}, S_t - S_{t-1})]$$

$$= a_0 + a_K \log(K_t) + a_L \log(L_t) + a_N \log(N_t) + a_H \log(H_t) + a_S \log(S_t)$$
$$- (1/2)[g_{KK}(K_t - dK_{t-1})^2 + g_{LL}(L_t - q_{t-1}L_{t-1})^2 + g_{NN}(N_t - q_{t-1}N_{t-1})^2 + g_{HH}(H_t - H_{t-1})^2 + g_{SS}(S_t - S_{t-1})^2]$$
$$- [g_{KL}(K_t - dK_{t-1})(L_t - q_{t-1}L_{t-1}) + g_{KN}(K_t - dK_{t-1})(N_t - q_{t-1}N_{t-1})$$
$$+ g_{KH}(K_t - dK_{t-1})(H_t - H_{t-1}) + g_{KS}(K_t - dK_{t-1})(S_t - S_{t-1})$$
$$+ g_{LN}(L_t - q_{t-1}L_{t-1})(N_t - q_{t-1}N_t) + g_{LH}(L_t - q_{t-1}L_{t-1})(H_t - H_{t-1})$$
$$+ g_{LS}(L_t - q_{t-1}L_{t-1})(S_t - S_{t-1}) + g_{NH}(N_t - q_{t-1}N_{t-1})(H_t - H_{t-1})$$
$$+ g_{NS}(N_t - q_{t-1}N_{t-1})(S_t - S_{t-1}) + g_{HS}(H_t - H_{t-1})(S_t - S_{t-1})]$$
$$+ a_1 t + v_t^f .$$

Terms in levels are the standard, Cobb-Douglas, components. Those in changes represent the output foregone when the levels of factors are varied. The parameter d is the survival rate of capital (one minus the depreciation rate); the variable q_t is the survival rate of labor (one minus the quit rate).

Consider the effect on output of varying the work week of capital, S_t . Varying S_t may involve costs of adjustment. As with hours, H_t , I expect the cost of adjusting the work week of capital to be small. Changing S_t , <u>ceteris paribus</u>, involves a rescheduling of production, which should be easy to do relative to changing the level of inputs.

Now consider the effect of the level of the work week of capital on output. Suppose that the production function exhibits constant returns to scale so that doubling capital and workers holding work week constant doubles output. This implies the parameter restriction $a_K + a_L + a_N = 1$. Suppose the firm wants to replicate the output produced by the plant not by doubling K_t , L_t , and N_t , but by doubling the work week of capital keeping the capital-to-labor ratio constant. That is, a second shift is added that replicates the first shift. To double output, the firm needs to double the labor input but only change the work week of capital holding capital stock fixed. Presuming labor is as productive at night as during the day, which is likely to be true as a first approximation, this scheme should just double output. This discussion abstracts from the adjustment costs.

This example illustrates a natural restriction on the parameters a_K , a_L , a_N , and a_S . If doubling L_t , N_t , and S_t while holding K_t (and H_t) constant doubles output, and $a_K + a_L + a_N = 1$, then a_K equals a_S . Such a result is highly intuitive. Extending the work week of capital creates capital services in exactly the same way as adding a new piece of equipment does. Therefore, K_t and S_t should have the same output elasticities. One would expect them to have very different costs of adjustment. In particular, one would expect the output foregone by adjusting the physical quantity of an input to far exceed the cost of changing the length of time that it operates.

The costs of increasing K_t and S_t are, however, very different. In particular, increasing K_t involves the purchase of additional equipment. How the cost of extending S_t is measured effects critically the estimate of a_S . I discuss issues of measuring factor cost in the next section.

3.2. Input Costs

The labor costs of a firm are a function of the number of employees, the number of hours they work, and the degree to which they work late shifts. That is, in addition to the premium for overtime there is a premium for hours worked on late shifts.

I assume that non-production workers are paid a fixed amount. The wage bill of production workers is given by the expression

$$w_t^* L_t H_t = w_t L_t H_t [w_0 + .5 w_1 (H_t/H_0) + w_2 (S_t/H_0)] + v_t^W \tag{3}$$

where w_t^* is the average real wage, w_t the straight-time wage, H_0 the average of H_t, and v_t^W an error term. The term in S_t captures the premium for work at hours other than the standard shift. It is paid when the work week of capital exceeds the work week of the typical worker.

The overtime premium, w_1, is typically 0.5. Information on the reported premium for work on late shifts is available in the Area Wage Survey. For 1973 through 1975, the average percentage pay differential for work on the second shift is 7.8 percent and for work on the third shift is 10.3 percent (see BLS Bulletin 1850-89, Area Wage Survey Summaries, 1975, p. 101).

The low value of the late-shift premium, w_2, which I confirm in the time-series estimates, poses theoretical difficulties for the model and estimates of the work week of capital. The premium is very small (compared to the overtime premium, for example). If w_2 as directly estimated represents the true marginal labor cost of extending the work week of capital, one is confronted with the puzzle discussed in the introduction: Why is the work week of capital so low? Given the low incremental labor cost, why is late shift work so rare? Put another way, if costs are indeed this low, then labor productivity on late shifts must be very low. Based on the low figure for w_2, the estimate of a_S is substantially lower than that of a_K.

Consider another alternative explanation for the low value of w_2. Firms in manufacturing operating late shifts typically rotate such work using a schedule that is essentially fixed among their existing work force. If late work is expected and rotation is customary, most of the premium needed to get workers to undertake it may be built into the average wage rather than explicitly made a function of late work. In this case, w_2 would be substantially underestimated. There is evidence in British data that such practice is customary (see Marris (1964, p. 137)).

Note that a similar argument cannot be made for overtime. The Fair Labor Standards Act requires that a standard premium be paid for overtime hours so these payments cannot be averaged into the straight-time wage. Hence, the measured data for overtime, unlike those for late shifts, more closely approximate the marginal cost to a firm. There are no such legal restrictions on shift premium.

The proposed solution to the puzzle of why there is so little shift work given that the average cost of labor does not increase much on late shifts is that the average cost does not replicate the marginal cost. I posit that the true marginal cost may be better proxied by the overtime premium. Alternatively, one can ask what is the estimate of marginal cost given the theoretical condition that a_K equal a_S. In the next section, I discuss the implications of these considerations.

In addition to there being variable cost for production workers, there is fixed cost of employing both production workers and non-production workers. These are any payments not a function of hours worked, which, in the case of non-production workers, are all the costs. The fixed compensation cost of a production worker is denoted s_t^L ; the compensation of a non-production worker is denoted as s_t^N .

The real purchase price of capital is given by

$$p_t^K = p_t(1 - t_t^K PVCCA_t - ITC_t) \tag{4}$$

where p_t^K is the real, after-tax purchase price of capital, p_t the real before-tax price, t_t^K the corporate tax rate, $PVCCA_t$ the present value of depreciation allowances, and ITC_t the investment tax credit rate. I assume that the survival rate of capital, d , is a constant. Given that the intensity of use of capital is variable in the model this assumption may be controversial. The advantage of making the assumption is that it makes the capital stock easily measured. The disadvantage is that it may lose one of the substantial costs of increasing the work week of capital. The construction of these data is discussed in the Appendix.

3.3. The Firm's Decision Problem

The firm maximizes the expected present discounted value of cash flow. The expected value of real, discounted, after-tax cash flow is given by

$$\begin{aligned} (5) \qquad & E_t \sum_{i=0}^{\infty} R_{t+i}\{f(K_{t+i}, L_{t+i}, N_{t+i}, H_{t+i}, S_{t+i}, K_{t+i} - dK_{t+i-1}, \\ & \quad L_{t+i} - q_{t+i-1}L_{t+i-1}, N_{t+i} - q_{t+i-1}N_{t+i-1}, \\ & \quad H_{t+i} - H_{t+i-1}, S_{t+i} - S_{t+i-1})(1 - t_{t+i}^K) \\ & - p_{t+i}^K(K_{t+i} - dK_{t+i-1}) \\ & - [w_{t+i}L_{t+i}H_{t+i}(w_0 + .5w_1(H_{t+i}/H_0) + w_2(S_{t+i}/H_0)) \\ & + s_{t+i}^L L_{t+i} + s_{t+i}^N N_{t+i}](1 - t_{t+i}^K)\} , \end{aligned}$$

where E_t denotes expectation taken conditional on information known to the firm at time t. The multi-period discount rate, R_{t+i}, is time varying and random. It is defined by $R_{t+i} = \prod_{j=1}^{i} \frac{1}{1+\rho_{t+j-1}}$ where ρ is the investor's required rate of return.[8] In the following, the discount rate from time t to $t+1$ is denoted as $r_t = \frac{1}{1+\rho_t}$.

For the firm to be acting optimally, the first-order conditions of the problem must hold. Differentiating (5) with respect to capital, production workers, non-production workers, hours of production workers, and the work week of capital yields the five following stochastic first-order conditions:

(6a)
$$E_t\{[a_K/K_t - g_{KK}(K_t - dK_{t-1}) - g_{KL}(L_t - q_{t-1}L_{t-1}) - g_{KN}(N_t - q_{t-1}N_{t-1}) - g_{KH}(H_t - H_{t-1}) - g_{KS}(S_t - S_{t-1})]y_t(1 - t_t^K) + [g_{KK}(K_{t+1} - dK_t) + g_{KL}(L_{t+1} - q_tL_t) + g_{KN}(N_{t+1} - q_tN_t) + g_{KH}(H_{t+1} - H_t) + g_{KS}(S_{t+1} - S_t)]y_{t+1}(1 - t_{t+1}^K)dr_t - p_t^K + dr_tp_{t+1}^K\} = 0$$

(6b)
$$E_t\{[a_L/L_t - g_{KL}(K_t - dK_{t-1}) - g_{LL}(L_t - q_{t-1}L_{t-1}) - g_{LN}(N_t - q_{t-1}N_{t-1}) - g_{LH}(H_t - H_{t-1}) - g_{LS}(S_t - S_{t-1})]y_t(1 - t_t^K) + [g_{KL}(K_{t+1} - dK_t) + g_{LL}(L_{t+1} - q_tL_t) + g_{LN}(N_{t+1} - q_tN_t) + g_{LH}(H_{t+1} - H_t) + g_{LS}(S_{t+1} - S_t)]y_{t+1}(1 - t_{t+1}^K)q_tr_t - [w_tH_t(w_0 + .5w_1(H_t/H_0) + w_2(S_t/H_0)) + s_t^L](1 - t_t^K)\} = 0$$

$$(6c)\quad E_t\{[a_N/N_t - g_{KN}(K_t - dK_{t-1}) - g_{LN}(L_t - q_{t-1}L_{t-1}) - g_{NN}(N_t - q_{t-1}N_{t-1})$$
$$- g_{NH}(H_t - H_{t-1}) - g_{NS}(S_t - S_{t-1})]y_t(1 - t_t^K) + [g_{KN}(K_{t+1} - dK_t)$$
$$+ g_{LN}(L_{t+1} - q_tL_t) + g_{NN}(N_{t+1} - q_tN_t) + g_{NH}(H_{t+1} - H_t)$$
$$+ g_{NS}(S_{t+1} - S_t)]y_{t+1}(1 - t_{t+1}^K)q_tr_t - S_t^N(1 - t_t^K)\} = 0$$

$$(6d)\quad E_t\{[a_H/H_t - g_{KH}(K_t - dK_{t-1}) - g_{LH}(L_t - q_{t-1}L_{t-1}) - g_{NH}(N_t - q_{t-1}N_{t-1})$$
$$- g_{HH}(H_t - H_{t-1}) - g_{HS}(S_t - S_{t-1})]y_t(1 - t_t^K) + [g_{KH}(K_{t+1} - dK_t)$$
$$+ g_{LH}(L_{t+1} - q_tL_t) + g_{NH}(N_{t+1} - q_tN_t) + g_{HH}(H_{t+1} - H_t)$$
$$+ g_{HS}(S_{t+1} - S_t)]y_{t+1}(1 - t_{t+1}^K)q_tr_t - w_tL_t[w_1(H_t/H_0)](1 - t_t^K)\} = 0$$

$$(6e)\quad E_t\{[a_S/S_t - g_{KS}(K_t - dK_{t-1}) - g_{LS}(L_t - q_{t-1}L_{t-1}) - g_{NS}(N_t - q_{t-1}N_{t-1})$$
$$- g_{HS}(H_t - H_{t-1}) - g_{SS}(S_t - S_{t-1})]y_t(1 - t_t^K) + [g_{KS}(K_{t+1} - dK_t)$$
$$+ g_{LS}(L_{t+1} - q_tL_t) + g_{NS}(N_{t+1} - q_tN_t) + g_{HS}(H_{t+1} - H_t)$$
$$+ g_{SS}(S_{t+1} - S_t)]y_{t+1}(1 - t_{t+1}^K)r_t - w_tL_tH_t(w_2/H_0)(1 - t_t^K)\} = 0$$

where

$$y_t = f(K_t,\ L_t,\ N_t,\ H_t,\ S_t,\ K_t - dK_{t-1},\ L_t - q_{t-1}L_{t-1},$$
$$N_t - q_{t-1}N_{t-1},\ H_t - H_{t-1},\ S_t - S_{t-1})\ .$$

The final equation of the model is the expression for the wage bill of production workers (3). I estimate equation (3) and the five first-order conditions (6) on data for U.S. manufacturing. The data are described in the Appendix.

4. Results

Estimation is carried out using non-linear three stage least squares. Realized values replace the conditional expectations. The error terms in the resulting equations are strictly expectational (except for the measurement errors v_t^W in equation (3)). In particular note that the productivity shock v_t^f from equation (2) does not enter the system (6). That is, the shock is embodied by the output data. The shock does not appear even if it is serially correlated.[9]

Data known at time t are valid instrumental variables. The instruments used are the level and logs of the factors, K_t, L_t, N_t, H_t, and S_t, the level of the factor prices, w_t, p^K, s^L, and s^N, the tax rate, t_t^K, survival rate of labor, q_t, the rate of return, r_{t-1}, and a constant and trend. Only the lagged rate of return is a valid instrument because r_t is not known until the beginning of period $t+1$. Although output appears in the equations, it, like the factors, is endogenous. Output is not used as an instrumental variable. Rotemberg (1984) shows that if the overidentifying restrictions of the model do not hold exactly what different lists of instruments can yield differing estimates. I discuss the importance of this issue in Section 5.1.

Table I gives the estimates of the parameters of the firm's decision problem. Column (i) gives estimates where there are no interrelated adjustment costs; column (ii) gives them for where there are no adjustment costs for the work weeks of capital and labor, H_t and S_t, but where the stock of capital, production workers, and non-production workers, K_t, L_t, and N_t, are subject to interrelated adjustment costs. All other interrelated adjustment costs always differ insignificantly and economically unimportantly from zero.

Consider the estimates of the parameters of equation (3) relating hours and shift work to wages. The estimate of the overtime premium, w_1 , is 0.42 in column (i) and 0.50 in column (ii). The estimate in column (ii) is exactly the theoretical value; the estimate in column (i) is close to it. Hence, the estimate of the function for the wage bill is broadly consistent with the stylized facts about overtime pay.

As anticipated in the theoretical discussion, the estimated premium for work on the late shift, w_2 , is small. The estimated premium of 0.05 in either column (i) or (ii) is consistent with the observation from the Area Wage Survey discussed above. The time series evidence does not rely on the information about the wage premium given in the Area Wage Survey. Both the evidence and the time series evidence point to a late shift premium substantially below that of the overtime premium. I discuss below the implications of the estimate of w_2 for the estimate of the output elasticity of the work week of capital.

Consider now the estimates of the output elasticities. The elasticities for production workers, a_L , and non-production workers, a_N , and the implied elasticity for capital, a_K , are consistent with their shares in national income. The elasticity of hours of production workers, H_t , is only slightly larger than that of the stock of production workers, L_t . If they were equal, production workers and their hours would be perfect substitutes.[10] In that case, the <u>level</u> of labor input could be treated as man-hours rather than workers and hours separately. The adjustment costs, which depend on the <u>changes</u> in inputs, and the contribution to the wage bill, are, of course, still very different for hours and workers.

The output elasticity of the work week of capital, a_S , is estimated to be only 0.026. Recall that the theoretical value of a_S is equal to that of a_K , which is plausibly estimated to be about one-quarter. Hence, if the estimate of the shift premium is taken from the data on the average wage, the productivity of shift work is estimated to be very low. The only way for the model to be consistent with that data is for the implied productivity of lengthening the work week of capital to be very low. This finding is consistent with the observed low apparent productivity of shift work found in studies discussed in footnote 2.

As argued above, the data on average wages may be misleading about the marginal cost of work on late shifts. Specifically, if firms and workers have an implicit contract to share work on late shifts equally among workers and if the pattern of such work is reasonably predictable, the straight-time wage might average a low wage for work during the day and a high wage for work during the night. In that case, the average wage is a poor indicator of the marginal cost of increasing shift work to the company.[11]

Consider the coefficients measuring the lost output from changing the amount of an input. Column (i) of Table I gives estimates without interrelated adjustment costs. Column (ii) gives estimates with interrelated adjustment costs for capital, production workers, and non-production workers. All other interrelated adjustment costs are insignificant and insubstantial. Indeed, the adjustment costs for hours and shifts are likewise insignificant and economically unimportant so they are left out of column (ii).

It is difficult to evaluate the size of the adjustment costs based on the parameters alone. It is informative to consider the marginal adjustment costs that they imply. Consider first the costs of adjustment in the equation for capital. The estimate of g_{KK} of 0.0008 in column (ii) implies an adjustment cost of 5.0 percent of the cost of investment. That is, for an average amount of investment, if there is no gross change in the amount of labor, output is reduced by 5.0 percent of amount of the investment. Average investment in the sample is 9.6 and average output is 62 measured in billions of 1972 dollars at quarterly rate. Therefore, the foregone output caused by adding the average amount of capital is less than one percent of average output. In particular, it is substantially smaller than other estimates (Summers (1981) and Meese (1980), for example).

The interrelated adjustment costs for capital and production workers and non-production workers are small: they are an order of magnitude smaller than the own-adjustment cost of capital. The sign of g_{KN} is negative, so the cost of adjusting capital is reduced when non-production workers are also being adjusted. That is, changing the stock of capital is facilitated by adding non-production workers.

It is more difficult to evaluate the adjustment costs of labor because although the stock is being adjusted, labor, unlike capital, is paid as a flow. In any case, one can compare the marginal adjustment costs to the flow cost of labor. In the case of production workers the adjustment costs are all small. Consider the estimate of 0.0403 for g_{NN} in (ii), that is, the adjustment cost for non-production workers. It is substantial: the marginal adjustment cost for the typical change in non-production workers is about 3 percent of output per quarter. Non-production workers receive about one quarter of output.

In summary, the adjustment costs of both the work week of capital and of labor are small. This result is not surprising given the relative ease of adjusting the schedule of production relative to adjusting the stock of an input. The cost of adjusting production workers is also small. The cost of adjusting capital is significant but substantially smaller than found in other studies. Thus, the estimate implies quicker adjustment of the capital stock than others find.

5. Extensions

5.1. Failure of the Overidentifying Restrictions

The J statistic given at the bottom of Table I is a test of the overidentifying restrictions of the model. It is distributed as chi-squared with degrees of freedom equal to number of instruments minus number of parmeters. There are 114 instruments (19 instruments times 6 equations) so the overidentifying restrictions are soundly rejected in all the specifications.

Rotemberg (1984) suggests that if the overidentifying restrictions of such a model are rejected, different instrument lists can yield widely different estimates. Specifically, if the weighting of the instruments is arbitrary, the estimates can have any probability limit. Note that the weighting scheme is determined here not arbitrarily, but optimally by three-stage least squares.

In order to evaluate the problem raised by Rotemberg's work, I present estimates of the model with alternative instrument lists. The first uses just price data; the second uses just quantity data. This division is economically as well as statistically meaningful. That is, the stochastic properties of prices and quantities are very different. In particular, factor quantities have high variance and are strongly pro-cyclic; factor prices vary little and are only weakly cyclic.

Estimates of the model with the two instruments lists are presented in columns (ii) and (iii) of Table II. The exact lists are given at the bottom of Table II. Both lists yield overidentification, but to a lesser degree than by taking the union of the lists. Column (i) replicates column (ii) of Table I for comparison. In columns (ii) and (iii), the parameters

w_1 and w_2 are constrained to have the same value as in column (i). The estimates of w_1 and w_2, the parameters of the equation for the wage bill (3), require both price and quantity data to be identified. Hence, they are left out of the experiment.

The estimates in column (ii) and column (iii) of Table II also strongly reject the overidentifying restrictions. Therefore, one cannot infer either that it is only the price data or only the quantity data that are invalid instruments. An economically meaningful way to evaluate the problem is to see how much the estimates change given the rejection.

The estimate of a_L, the production workers' output elasticity, changes little over the choice of instruments. Likewise, the coefficient a_H is stable. The coefficient a_N, the output elasticity for non-production workers, and consequently capital's implied output elasticity, does change substantially. The implied a_K is column (ii) is 0.18 which is somewhat lower than conventional estimates. The coefficients in the adjustment cost change more, but they are less precisely estimated in the first instance. The most serious change occurs in g_{KK}, where the estimate not using price data implies a very high adjustment cost.

Errors in variables can be analyzed as a failure of the over-identifying restrictions. The work week of capital contains a measurement error because of the distribution of annual data to quarterly frequency. The importance of this problem can be evaluated by considering estimates where S_t is excluded from the instrument list. These estimates may be consistent even if S_t is measured with error. In column (iv) of Table 2, I present estimates of the model where S_t and its log are excluded from the instrument list. The estimates are virtually identical to those in column (i). Hence, the measurement error does not have a quantitatively important affect on the results.

The results of the analysis of varying the instruments is indecisive. In particular, it does not isolate the invalid instruments as either belonging to the price or quantity subset. With either set of instruments, about half the coefficients are remarkably stable. The other half change by amounts that would importantly affect the dynamics implied by the model, but they never change so much as to take on values that could be excluded *a priori*. Moreover, it is a minor victory that I am able to arrive at a not entirely implausible set of estimates with the price data alone as instruments even though they vary much less than the quantities. In any case, one is less confident about the point estimates of the parameters that change importantly.

5.2. Aggregation Problem

Problems with using aggregate data are pervasive in macroeconomics. There is typically a tension between the theoretical discussion and the empirical implementation. The aggregation problem is, perhaps, more severe or more obvious, in the application to shift work. Specifically, firms may be heterogeneous in their policies toward shift work. This section evaluates the consequences of this aggregation problem for the analysis in this paper.

Suppose that there are two types of firms, one that always works only one shift and one that has varying shifts. Let S_1 be the constant work week of the first type of firm and S_2 be the work week of the second type of firm. I assume that the fraction of type one firms is a constant, b . Then

(7) $$S = bS_1 + (1-b)S_2 .$$

All the variation in S comes from the second type of firm. Substituting (7) into the objective function (5) and differentiating with respect to the choice variable, S_2, yields the following modified first-order condition for S:

(6e') $$a_S(1-b)Y_t/S_t = w_tL_tH_tw_2/H_0 .$$

In light of the estimates of the adjustment cost coefficients, I set them to zero. The tax rate cancels so (6e') is the familiar marginal product equals marginal cost condition. The estimates of a_S in Table 2 do not allow b to be separately identified. That b is large is another possible explanation for why a_S is estimated to be so much lower than a_K when w_2 is freely estimated. If many firms, for whatever reason, never work late shifts, then the interpretation that shift work is unproductive seems to be correct. In any case, b can be regarded as a normalization of equation (6e') because a_S is a free parameter. Therefore, the reasons discussed in footnote 11, whether there is an aggregation problem of this type affects the interpretation of the coefficients but does not change the dynamics implied by the estimated model.

6. Dynamics

In this section, I explore the dynamics implied by the estimates of the model. In particular, I examine the effect of changes in the price of capital and investors' required rate of return on the demand for capital and its work week. The estimates have broader application, but the aim here is to study the demand for capital. Estimating the first-order conditions of the model allows more realistic parameterizations than estimating the solution directly. The model cannot, however, be solved analytically. To study the dynamics, I linearize the first-order conditions and examine the properties of the solution of the linearized system.

The exact procedure I follow is (a) linearize the estimates of equations (6) and (3) from Table I, column (ii), about the sample average values for the variables;[12] (b) put the linearized system in the canonical form of Blanchard and Kahn (1980) and solve it; and (c) examining how the factor demands change when the price affecting them are changed.[13]

Some assumption must be made to close the model. In particular, though the representative firm in the manufacturing sector is a price-taker in the labor market, the sector as a whole does not face elastic labor supply. To the contrary, labor supply is highly inelastic, and hence bounds the response to a shock that could otherwise make the economy expand indefinitely. I add a final relationship to the system to take into account inelastic labor supply. I assume that the labor supply curve has a constant elasticity of 0.1.[14] The equation that labor supply equals labor demand is solved with equations (6) and (3).

I consider the effect of changing both the purchase price of capital and the investors' required rate of return on the demand for capital and its work week. I consider decreases in these two components of the implied cost of capital, but the results are exactly reversed for increases. A decrease in the required rate of return of investors increases the discount rate and hence increases the value of the firm. The discount rate, r_t , enters the model highly non-linearly. As I outline above, this problem is overcome by linearizing the system. Bernanke (1983) uses a similar procedure.

Tables III through VI give the response of the capital stock and its work week to different changes in the price of capital and the rate of return. Figures 1 through 4 plot the responses. The changes can be thought as changes in tax rates. A decrease in the purchase price of capital can arise when the investment tax credit is increased or depreciation allowances are liberalized. A decrease in investors' required rate of return may occur when the tax rate on investment income is reduced.

In Table III and Figure 1, I present the change in the demand for capital and its work week for a permanent, ten percent reduction in the cost of capital. The reduction is unexpected; once it occurs, it is expected to, and indeed does, last indefinitely. The first column gives the change in the price. The second and third columns give the percent change in the stock and work week of capital. The fourth and fifth columns give the levels of the stock and work week (deviation from steady state). In the long run, the capital stock increases by 3.1 percent and the work week of capital increases by 9.7 percent implying respective elasticities of about one-third and one. The capital stock is costly to adjust so it responds only gradually to the change in price. Half the adjustment has taken place after five quarters, which is much more rapid than found in other studies. In a similar experiment, Summers (1981) finds half the adjustment taking twenty years. The magnitudes of the long run changes are comparable with those Summers estimates.[15]

The work week of capital is costless to adjust. Indeed, it overshoots its steady state value by 17 percent in quarter 3. It then gradually falls to its steady state value. For the entire period of adjustment, the firm has a lower capital stock than it desires given the new factor prices. Hence, it correspondingly increases the utilization of its stock by expanding its work week.

In Figure 2 and Table IV, I present the response of capital to the ten percent decrease in its cost that is expected in quarter 1 to be permanent. In quarter 9, the price of capital unexpectedly increases to its original level. Through quarter 8, the dynamics are exactly as in the first example. In quarter 9, when the firms discover that the reduction is only temporary, they suddenly have capital substantially above the steady state value of zero. Because of the adjustment cost, the stock only gradually returns to its steady state value. On the other hand, the rate of utilization is free to adjust and therefore overshoots to offset the capital stock being above its steady-state value. The work week approaches the steady state from below.

Figure 3 and Table V give the response of capital to a permanent decrease in investors' required rate of return. It has a large effect on the demand for capital because it increases the present discounted value of cash flow as well as reducing the implied rental rate on capital. The steady state increase in the capital stock from a ten percent reduction in investors' required rate of return is 20.3 billion 1972 dollars, or ten percent of the average stock.[16] Because of the linearity of the solution, the relative changes of the stock and the work week and the rates of adjustment are exactly as in Figure 1.

In a final experiment, I consider an expected, future, permanent reduction in the investors' required rate of return. But when the reduction is expected to take place, it is revealed that no reduction will take place. Hence, the interest rate never changes. These dynamics are displayed in Figure 4 and Table VI. Such a scenario could occur if the government announces a tax cut on investors' income to take effect in 9 quarters, if the firms believe the government, and if the government then reneges on its commitment. This is an effective policy for temporarily increasing the capital stock, but one which cannot be repeated often (see Fischer (1980)). Future flows from the current capital stock are discounted at a lower rate, so the stock increases. In quarter 9, the firms discover they have been misled. They only gradually reduce their capital stock, but immediately adjust its utilization. Indeed, the utilization rate overshoots its steady state value and approaches it from below.

I find a substantial effect of the real interest rate and the purchase price of capital on the demand for capital. The standard view is, however, that "The rental price of capital, a conglomeration of interest rate and tax variables, is not very useful in explaining quarterly data of business fixed investment in the United States over the past twenty-five years" (Clark (1979, p. 104)). Clark does not conclude that the cost of capital is unimportant in theory, but that they do not vary enough given slow adjustment of the stock to be important in the data.

The findings of this paper provide important challenges to this standard view. First, I find a substantial effect of interest rates and factor prices on the demand for capital. Second, the adjustment costs I estimate are small enough so that the capital stock can respond somewhat to business-cycle frequency changes in interest rates and prices. Third, lower interest rates increase the present discounted value of cash flow so future labor services, which will be associated with the capital services, are also more highly valued.

It is useful to consider why prices and interest rates are important in my model but not in non-structural reduced forms such as considered by Clark. (See also Bernanke (1983) for a related discussion.) My procedure is as follows: I specify a structural model; I estimate the first-order conditions of the model with a parameterization that is too complicated to solve explicitly; and I linearize the estimated system to study its dynamics. Clark estimates linear reduced forms. Although the linear reduced form may correspond to some structural model, estimating it is highly inefficient given the strong restrictions (in equation (6) for example).[17] Consider equation (6a). The interest rate enters the implied rental cost of capital by multiplying p_t^K, but also by multiplying the future value of the factors. The implied reduced form is highly non-linear in variables and parameters. Therefore, it is asking much of the data to trace out the true relation by estimating a linearized reduced form. On the other hand, it is easy to impose the appropriate restrictions by estimating the first-order condition. By linearizing after estimating, I impose the restrictions, at least locally, when examining the effect of prices and interest rates on investment.

7. Conclusion

This paper provides the analytic mechanism and empirical evidence to analyze the dynamic demand for capital, labor, and their levels of utilization. The work week of capital measures the utilization of the stock. It is constructed using data on the amount of shift work.

The productivity of extending the work week of capital must be low relative to the costs given how few late shifts are worked. The average wage premium for working on late shifts is low. This implies that the output elasticity will be estimated to be low. I consider two alternative explanations of these facts, both of which are consistent with the data, and both of which imply the same macroeconomic dynamics. The first is that the marginal wage premium is much higher than the average wage premium. The second is that there is an aggregation problem if some firms have rules against late shifts.

The estimated adjustment costs are also consistent with theory. The adjustment cost on capital is again estimated to be much lower than found in other studies, implying more plausible rates of response to stocks. As with hours of production workers, the work week of capital is virtually costless to adjust. Thus, it provides a margin to easily absorb transitory shocks to product or factor prices.

Additionally, when the work week of capital is taken into account, the output elasticity of the work week of labor is not substantially larger than that of the stock of labor. Hence, the greater marginal product of hours (H_t) compared to workers (L_t) the work week of capital is excluded can be understood to arise because those extra hours imply a lengthening of the work week of capital, not because a current worker working an extra hour is more productive than a new worker. The estimates of (6) provide some justification for letting hours and workers enter multiplicatively <u>in levels</u> in the production function. On the other hand, their adjustment costs and contribution to labor's compensation are very different.

The work week of capital is essentially costless to adjust so it will respond immediately to shocks whereas the stock of capital will respond slowly. The plausibly estimated adjustment costs imply that the rate of adjustment is not instantaneous, but is much more rapid than as estimated in other studies. The work week of capital provides an extra margin along which to adjust. In the response to a shock, the work week of capital will overshoot to compensate for the slow adjustment of the stock. The magnitude of the overshooting is about twenty percent.

I find a large effect on the capital stock of changing interest rates and factor prices. These estimates provide a challenge to the standard view that prices are not important in determining demand for capital. The long run elasticity of the capital stock with respect to the price of capital is estimated to be about thirty percent. The elasticity with respect to the required rate of return is about one.

TABLE I

Estimate of First-order Conditions (6)
and Equation for the Wage Bill (3)
1955 QIII through 1980 QIII

	(i)	(ii)
w_0	.76 (.016)	.72 (.023)
w_1	.42 (.030)	.50 (.044)
w_2	.05 (.001)	.05 (.001)
a_L	.47 (.005)	.47 (.001)
a_N	.28 (.004)	.27 (.004)
a_H	.48 (.008)	.48 (.011)
a_S	.027 (.001)	.026 (.001)
g_{KK}	.0005 (.0004)	.0008 (.0006)
g_{LL}	*	-.0009 (.0009)
g_{NN}	.1275 (.0296)	.0403 (.0302)
g_{HH}	-.0001 (.0001)	
g_{SS}	*	
g_{KL}		.0016 (.0005)
g_{KN}		-.0020 (.0019)
g_{LN}		.0149 (.0036)
J	358	362

Standard errors in parentheses.
J test of overidentifying restrictions (see Hansen (1982)).

*indicates magnitude of estimate < .00005.

TABLE II

Estimate of First-order Conditions (6)
and Equation for the Wage Bill (3)
1955 QIII through 1980 QIII
Alternative Instrument Lists

	(i)	(ii)	(iii)	(iv)
Instrument list:	A & B	A	B	C
w_0	.72 (.023)	.72 (.0004)	.72 (.0004)	.72 (.0004)
w_1	.50 (.044)	.50	.50	.50
w_2	.05 (.001)	.05	.05	.05
a_L	.47 (.001)	.47 (.008)	.47 (.005)	.47 (.005)
a_N	.27 (.004)	.35 (.020)	.27 (.004)	.27 (.004)
a_H	.48 (.011)	.48 (.007)	.47 (.007)	.48 (.007)
a_S	.026 (.001)	.026 (.0004)	.025 (.0004)	.026 (.0004)
g_{KK}	.0008 (.0006)	.0005 (.0008)	.0026 (.0008)	.0008 (.0007)
g_{LL}	-.0009 (.0009)	-.0046 (.0033)	.0009 (.0014)	-.0007 (.0009)
g_{NN}	.0403 (.0302)	.7641 (.3260)	.0873 (.0507)	.0448 (.0310)
g_{KL}	.0016 (.0005)	.0023 (.0011)	.0034 (.0007)	.0018 (.0005)
g_{KN}	-.0020 (.0019)	-.0146 (.0128)	-.0013 (.0029)	-.0015 (.0019)
g_{LN}	.0149 (.0036)	.0382 (.0244)	.0169 (.0063)	.0155 (.0036)
J	362	176	262	317
k	114	48	72	102

Standard errors in parentheses.

J test of overidentifying restrictions (see Hansen (1982)), which is distributed as chi-squared with k degrees of freedom where k is the number of instruments with time equations.

In columns (ii), (iii), and (iv), w_1 and w_2 are constrained (see text).

*indicates magnitude of estimate < .00005.

Instrument lists:

A constant, trend, t^K, w, p^K, r, s^L, s^N

B constant, trend, K, L, N, H, S, log(K), log(L), log(N), log(H), log(S)

C constant, trend, t^K, w, p^K, r, s^L, s^N, q, K, L, N, H, log(K), log(L), log(N), log(H) (that is, all excluding S and log(S)).

TABLE III

Response of Capital to a Permanent, Unexpected Decrease in the Price of Capital

Quarter	Price	Percent Stock	Percent Work Week	Level Stock (10^9 72$)	Level Work Week (hours)
0	0.0	0.0	0.0	0.0	0.0
1	-10.0	0.4	1.6	0.9	0.9
2	-10.0	0.6	10.4	1.3	5.8
3	-10.0	0.9	11.2	1.9	6.2
4	-10.0	1.2	11.1	2.5	6.1
5	-10.0	1.4	10.9	2.9	6.0
6	-10.0	1.6	10.7	3.3	5.9
7	-10.0	1.8	10.6	3.7	5.8
8	-10.0	2.0	10.4	4.0	5.8
9	-10.0	2.1	10.3	4.2	5.7
10	-10.0	2.2	10.3	4.5	5.7
11	-10.0	2.3	10.2	4.7	5.6
12	-10.0	2.4	10.1	4.8	5.6
13	-10.0	2.5	10.1	5.0	5.6
14	-10.0	2.5	10.0	5.1	5.5
15	-10.0	2.6	10.0	5.3	5.5
16	-10.0	2.6	9.9	5.4	5.5
17	-10.0	2.7	9.9	5.5	5.5
18	-10.0	2.7	9.9	5.6	5.5
19	-10.0	2.8	9.9	5.6	5.4
20	-10.0	2.8	9.8	5.7	5.4
30	-10.0	3.0	9.7	6.1	5.4
40	-10.0	3.1	9.7	6.3	5.3
Infinity	-10.0	3.1	9.7	6.3	5.3

TABLE IV

Response of Capital to an Unexpected Decrease in Its Price Expected to be Permanent but Actually Lasting Eight Quarters

		Percent		Level	
Quarter	Price	Stock	Work Week	Stock (10^9 72$)	Work Week (hours)
0	0.0	0.0	0.0	0.0	0.0
1	-10.0	0.3	-0.1	0.7	0.0
2	-10.0	0.5	10.3	1.1	5.7
3	-10.0	0.8	11.3	1.7	6.2
4	-10.0	1.1	11.2	2.3	6.2
5	-10.0	1.4	11.0	2.7	6.0
6	-10.0	1.6	10.8	3.2	5.9
7	-10.0	1.7	10.6	3.5	5.9
8	-10.0	1.9	10.5	3.8	5.8
9	0.0	1.8	-0.1	3.7	0.0
10	0.0	1.6	-1.2	3.2	-0.6
11	0.0	1.4	-1.2	2.8	-0.6
12	0.0	1.2	-0.9	2.4	-0.5
13	0.0	1.1	-0.8	2.1	-0.4
14	0.0	0.9	-0.7	1.9	-0.4
15	0.0	0.8	-0.6	1.7	-0.3
16	0.0	0.7	-0.5	1.5	-0.3
17	0.0	0.7	-0.4	1.3	-0.2
18	0.0	0.6	-0.4	1.2	-0.2
19	0.0	0.5	-0.3	1.1	-0.2
20	0.0	0.5	-0.3	0.9	-0.2
25	0.0	0.3	-0.2	0.6	-0.1
30	0.0	0.2	-0.1	0.3	-0.1
40	0.0	0.1	0.0	0.1	0.0
50	0.0	0.0	0.0	0.0	0.0
Infinity	0.0	0.0	0.0	0.0	0.0

TABLE V

Response of Capital to a Permanent, Unexpected Decrease in Investors' Required Rate of Return

Quarter	Percent: Rate of Return	Percent: Stock	Percent: Work Week	Level: Stock (10^9 72$)	Level: Work Week (hours)
0	0.0	0.0	0.0	0.0	0.0
1	-10.0	1.9	32.8	3.9	18.1
2	-10.0	3.0	35.6	6.0	19.6
3	-10.0	3.9	35.0	7.9	19.3
4	-10.0	4.7	34.2	9.5	18.9
5	-10.0	5.3	33.6	10.8	18.5
6	-10.0	5.9	33.1	11.9	18.2
7	-10.0	6.3	32.6	12.9	18.0
8	-10.0	6.8	32.3	13.7	17.8
9	-10.0	7.1	32.0	14.4	17.6
10	-10.0	7.4	31.7	15.1	17.5
11	-10.0	7.7	31.5	15.6	17.4
12	-10.0	7.9	31.3	16.1	17.3
13	-10.0	8.2	31.2	16.6	17.2
14	-10.0	8.4	31.1	17.0	17.1
15	-10.0	8.5	31.0	17.3	17.1
16	-10.0	8.7	30.9	17.6	17.0
17	-10.0	8.8	30.8	17.9	17.0
18	-10.0	8.9	30.7	18.1	16.9
19	-10.0	9.0	30.6	18.4	16.9
20	-10.0	9.1	30.6	18.6	16.9
30	-10.0	9.7	30.2	19.7	16.7
40	-10.0	9.9	30.1	20.1	16.6
50	-10.0	10.0	30.1	20.3	16.6
Infinity	-10.0	10.0	30.0	20.3	16.6

TABLE VI

Response of Capital to a Future, Permanent Decrease in Investors' Required Rate of Return When the Decrease Does Not Occur

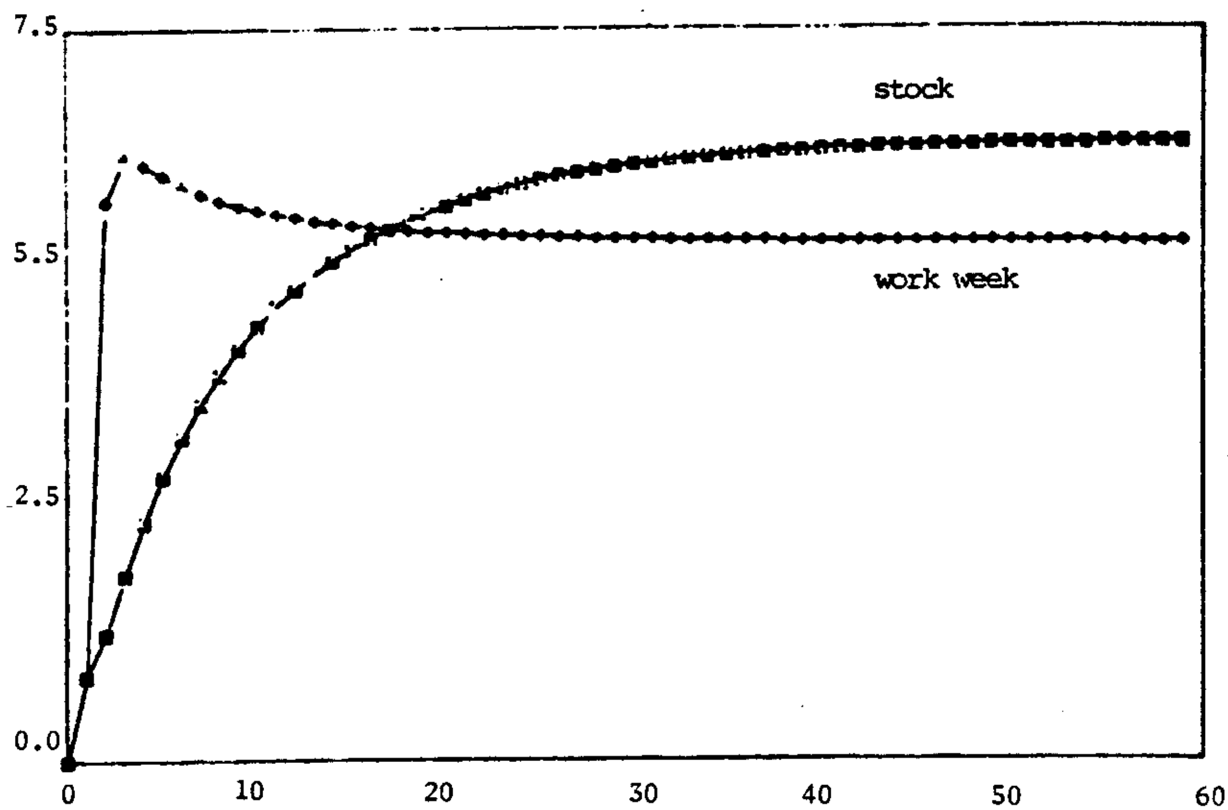
Quarter	Percent: Rate of Return	Percent: Stock	Percent: Work Week	Level: Stock (10 72$)	Level: Work Week (hours)
0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.4	5.2	0.8	2.9
2	0.0	0.8	5.6	1.7	3.1
3	0.0	1.4	5.3	2.8	2.9
4	0.0	1.9	5.0	3.9	2.7
5	0.0	2.4	4.6	4.9	2.5
6	0.0	2.9	4.3	5.8	2.4
7	0.0	3.3	3.9	6.7	2.2
8	0.0	3.7	3.6	7.4	2.0
9	0.0*	3.3	-1.7	6.7	-0.9
10	0.0	2.9	-2.0	6.0	-1.1
11	0.0	2.6	-1.8	5.3	-1.0
12	0.0	2.3	-1.6	4.7	-0.9
13	0.0	2.1	-1.4	4.2	-0.8
14	0.0	1.8	-1.2	3.7	-0.7
15	0.0	1.6	-1.1	3.3	-0.6
16	0.0	1.5	-0.9	3.0	-0.5
17	0.0	1.3	-0.8	2.7	-0.5
18	0.0	1.2	-0.7	2.4	-0.4
19	0.0	1.1	-0.6	2.2	-0.4
20	0.0	1.0	-0.6	1.9	-0.3
25	0.0	0.6	-0.3	1.1	-0.2
30	0.0	0.3	-0.2	0.7	-0.1
40	0.0	0.1	-0.1	0.2	0.0
50	0.0	0.0	0.0	0.1	0.0
Infinity	0.0	0.0	0.0	0.0	0.0

*Ten percent decrease expected in quarter 9, but it does not occur.

FIGURE 1

Response of Capital to a Permanent, Unexpected Decrease

in the Price of Capital

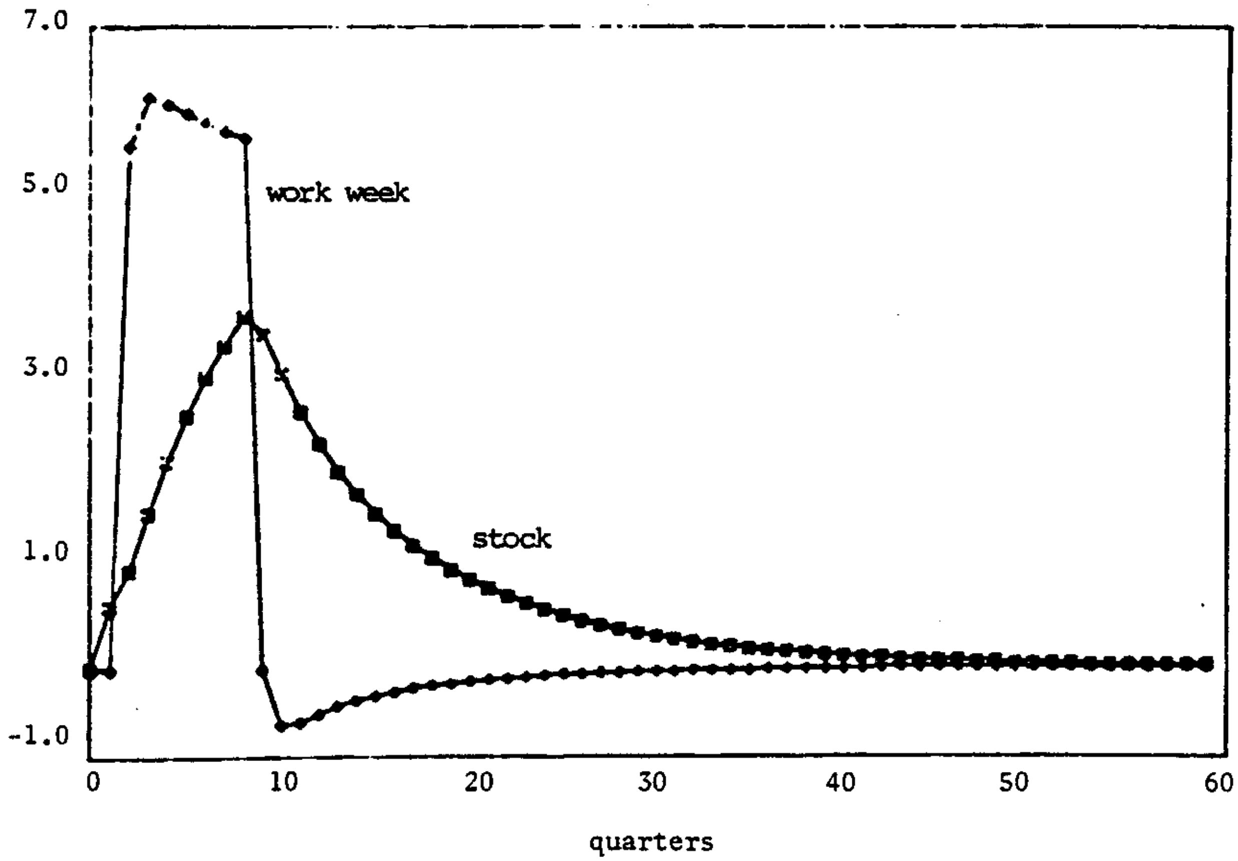


Note: Stock measured in billions of 1972 dollars.
Work week measured in hours.

FIGURE 2

Response of Capital to an Unexpected Decrease in Its Price

Expected to be Permanent but Actually Lasting Eight Quarters

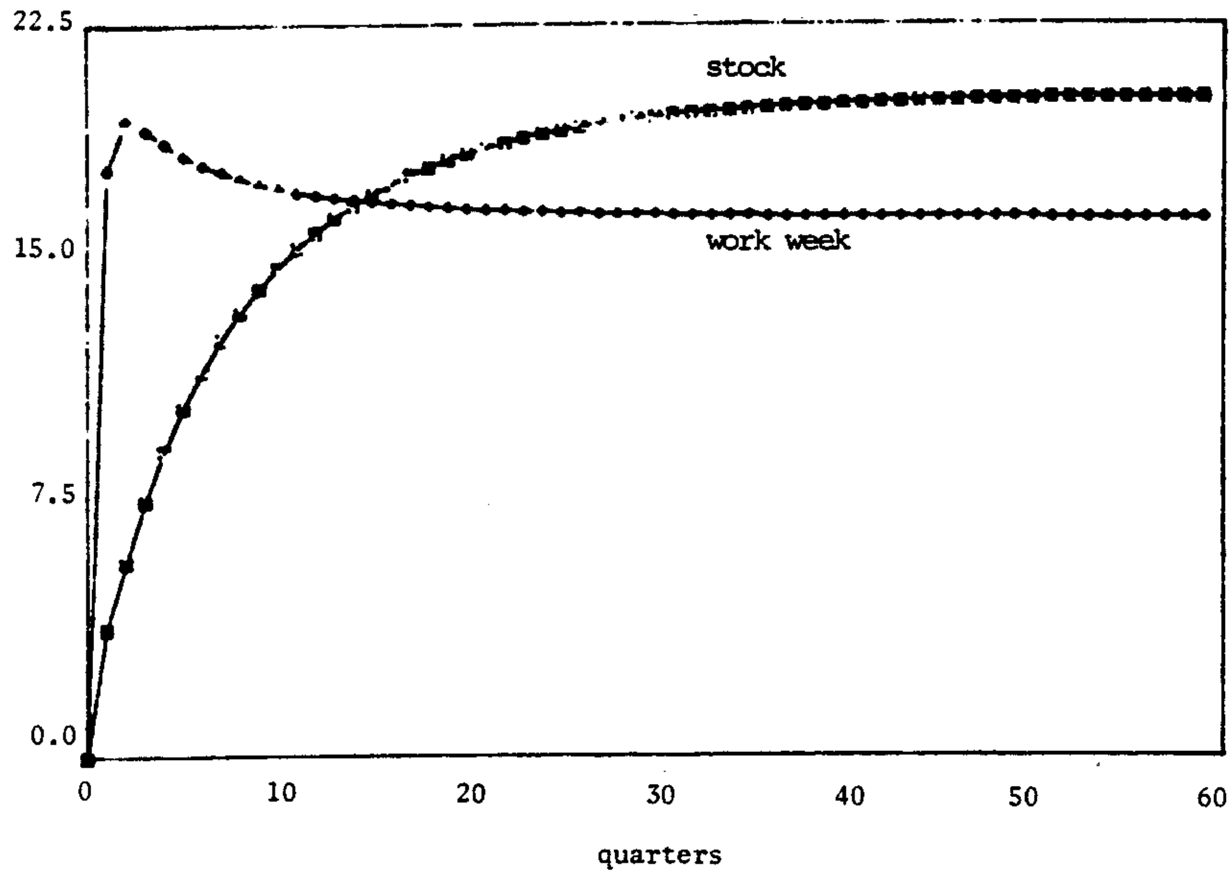


Note: Stock measured in billions of 1972 dollars.
Work week measured in hours.

FIGURE 3

Response of Capital to a Permanent, Unexpected Decrease

in Investors' Required Rate of Return

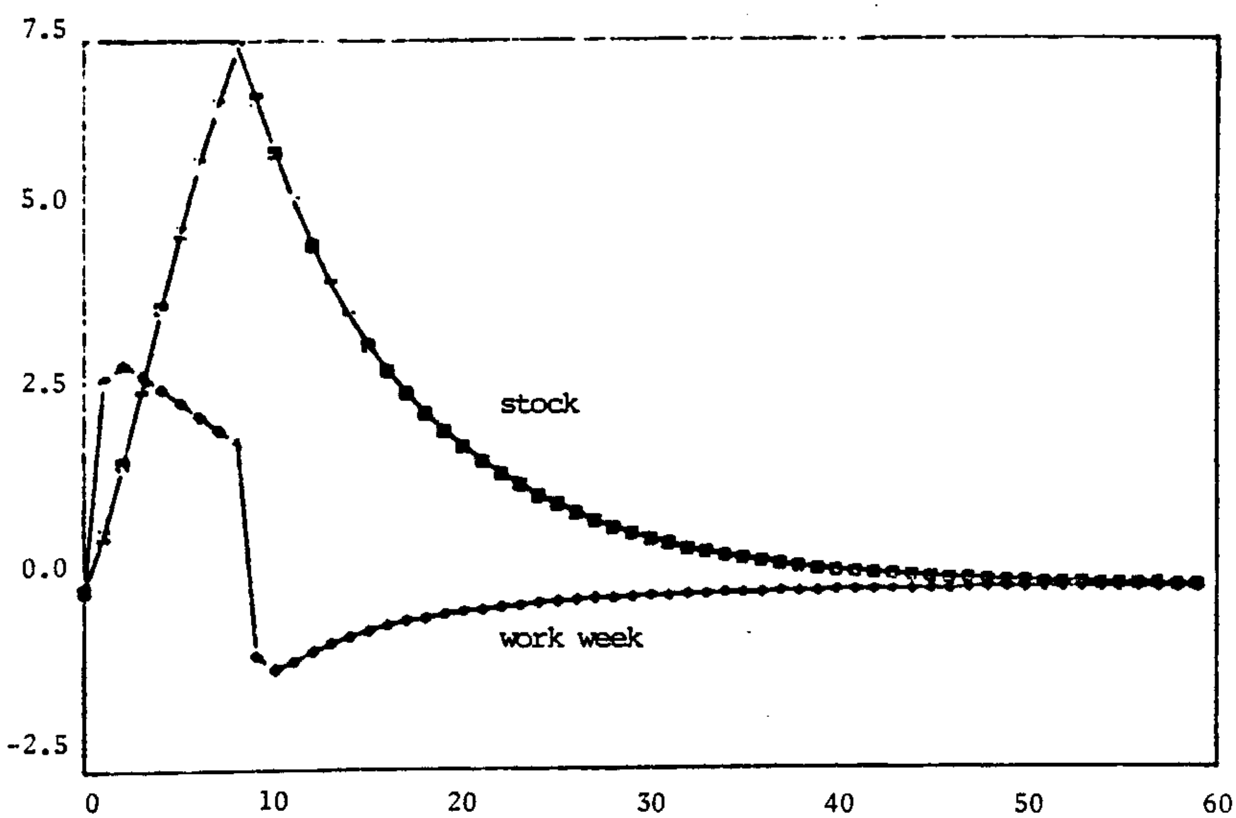


Note: Stock measured in billions of 1972 dollars.
Work week measured in hours.

FIGURE 4

Response of Capital to a Future, Permanent Decrease in

Investors' Required Rate of Return When the Decrease Does Not Occur



Note: Stock measured in billions of 1972 dollars.
Work week measured in hours.

APPENDIX

A. Capacity Utilization Data

This Appendix discusses how published data on capacity utilization do not represent directly data on capital utilization. Ideally, one would have an independent measure of the rate of utilization of each of labor and capital. At any point in time, the firm has four choices, how much labor and capital to hire or buy, and at what rate to use each. Because higher utilization has a cost, it does not always pay to have maximum utilization.

There are no published figures at the macroeconomic level for utilization of capital analogous to average hours of labor. An analogous figure would measure the physical utilization of the capital. For a machine it could measure the rate of speed of operation or percentage of the time it is in operation. For a structure, it could measure the percentage of the time it is in use. The published figures for capacity utilization reflect the ratio of output to "potential output" rather than the actual utilization of capital. One could imagine using energy consumption as a proxy for capital utilization. Such a procedure again asks how much of an alternative factor is utilized.

The Fed constructs its index of capacity utilization by dividing its index of industrial production by an index of capacity measured in units of output. (See the Federal Reserve System, Measures of Capacity and Capacity Utilization (1978) for details.) It bases the index of capacity on McGraw-Hill surveys and the BEA's data on capital stock. The capacity figures are available only annually; the Fed interpolates the within-year figures. Therefore, all the within-year variation, and most of the year-to-year variation in the Fed's index of capacity utilization, is caused by variation in output. Indeed, the concept being measured is close to output divided by potential or trend output.

The BEA constructs its series for capacity utilization from a quarterly survey of firms. In the survey's questionnaire, the BEA fails to define what it means by capacity utilization but it "believe[s] that most respondents use a measure of 'maximum practical capacity.'" (See Bureau of Economic Analysis, Handbook of Cyclical Indicators (1977, p. 25), emphasis added.) The BEA defines maximum practical capacity as output where a standard work-week's of labor to be supplied.

Variations in both measures of capacity utilization come mainly from the amount of labor input. Therefore, the choice of measured capacity utilization is not independent from the choice of other inputs.

B. Data for the Estimates

The data are quarterly for manufacturing from 1955 through 1980. The output data (y_t) are the Federal Reserve Board's quarterly index of output in manufacturing scaled so it equals annual NIPA output in 1967. The quarterly data for investment is from the Survey of Current Business. Structures and equipment are aggregated. I construct the capital stock data (K_t) using a fixed depreciation rate of 0.0175 per quarter and a benchmark net capital stock of 311.8 billion 1972 dollars at the end of 1981 (see the Survey of Current Business (October 1982, p. 33)). This depreciation rate is also imposed in estimating the Euler equations.

The data for employment (L_t, N_t), wages, the quit rate, and hours are from the BLS establishment survey. The wage (w_t) series is the average straight-time rate per hour for the production workers. The data on average hourly earnings (w_t^*) are also used in equation (3). The hours (H_t) series is total average weekly hours. Hours are multiplied by the number of weeks in the quarter in the marginal cost expressions in the Euler equations to express cash flow at quarterly rate. To construct the fixed cost of employing a worker (S^L and S^N), I divide the compensation minus wages, salaries, and contribution to social insurance into the number of workers using annual national income and product accounts data. These costs include employer contributions to pensions and health insurance. The annual NIPA figures are interpolated.

The expression for the price of capital is given in equation (4). The purchase price (P_t) is the implicit deflator from the BEA. The quarterly series for the present value of depreciation allowances ($PVCCA_t$) and the investment tax credit (ITC_t) are those computed by Data Resources Inc. The present value of depreciation allowances are computed using the technique outlined by Jorgenson and Sullivan (1981). Expected tax savings assuming current law remains unchanged are discounted by using the firm structure of interest rates. Data for the required rate of return are discussed in footnote 8.

Construction of the work week of capital is discussed in detail in the text. The data are given in Table A-1.

TABLE A-1

The Work Week of Capital: S_t
United States Manufacturing Industry
(hours)

	QI	QII	QIII	QIV
1952	54.8	56.1	55.9	55.7
1953	55.1	55.4	55.4	55.3
1954	53.4	49.9	49.1	52.7
1955	54.3	54.6	54.7	54.8
1956	55.1	55.2	55.2	55.3
1957	54.8	54.9	54.6	52.8
1958	54.0	52.8	52.9	53.0
1959	55.3	54.4	53.5	53.3
1960	55.0	53.9	53.5	52.8
1961	53.6	53.6	53.8	53.9
1962	55.1	54.8	54.8	54.8
1963	55.0	55.1	55.1	55.0
1964	55.2	55.2	55.4	55.5
1965	56.9	55.5	55.9	56.3
1966	57.4	57.0	57.3	57.5
1967	57.8	55.6	56.3	56.5
1968	58.9	56.3	57.1	57.8
1969	54.6	54.8	55.4	55.0
1970	54.4	53.5	53.8	53.2
1971	53.7	53.8	54.3	54.8
1972	55.4	56.0	55.6	56.1
1973	56.0	56.2	56.2	56.3
1974	56.0	55.0	56.0	54.6
1975	54.1	54.3	55.1	55.7
1976	55.2	54.9	55.0	54.9
1977	54.9	55.7	55.7	55.9
1978	55.0	56.1	56.2	56.4
1979	56.5	55.0	55.6	55.4
1980	55.5	54.0	53.7	54.7
1981	54.4	54.6	54.1	53.2
1982	53.2	53.8	53.5	53.4

FOOTNOTES

[1]This paper is a revision of the second chapter of my 1984 M.I.T. Ph.D dissertation. I am very grateful to my committee, Stanley Fischer, Jerry Hausman, and Olivier Blanchard, and to Andrew Abel, Ernst Berndt, Zvi Griliches, N. Gregory Mankiw, James Poterba, David Romer, Julio Rotemberg, and Lawrence Summers for their extensive comments and discussion. I gratefully acknowledge the financial suppose of the National Science Foundation.

[2]It has long been observed that most capital in most countries is idle most of the time (see Foss (1963, 1981) and Betancourt and Clague (1981)). For example, the average work week of capital for United States manufacturing industries is 55 hours according to the series to be discussed below. This low level of utilization is common across countries. Moreover, businesses typically plan investment so that most capital is idle most of the time (see Marris (1964, 1970)). That is, many firms plan to operate only one shift. Given that the productivity of capital is not constrained by preference, custom, law, or biology as is labor, it seems surprising that the work week of capital only slightly exceeds that of labor. The biological and social constraints on shift work are discussed in Mott, et al. (1965), Maurice (1975), and Hedges and Sekscenski (1979). Mott, et al. provide survey evidence on attitudes of workers and their families toward work on late shifts. Work on late shifts yields substantial disutility beyond work in the day, but the added disutility does not appear to be enough to explain the low level of shift work. Maurice provides a summary of law about shift work for a sample of developed countries. Hedges and Sekscenski survey the

biological literature on the physiological effects of work on late shifts. Winston (1974, 1982) surveys the theoretical literature on the utilization puzzle. Betancourt and Clague study the choice of shift work in a static context.

[3]If there is only one shift then average hours of workers would also be the average hours of capital.

[4]The sources of the annual data on the distribution of shift work is the Bureau of Labor Statistics, Area Wage Surveys: Metropolitan Areas, United States and Regional Summaries, various years. [The BLS report numbers are 1660-92, 1685-92, 1725-96, 1775-98, 1795-29, 1850-89, 1900-82, and 1950-77, Table B-1.] I am grateful to the BLS for providing me with unpublished data for years after 1978. Murray Foss provided me with part of an unpublished monograph which alerted me to these data.

[5]In the estimates of the model itself, the data are not detrended.

[6]Feldstein and Foot (1971) and Eisner (1978) include capacity utilization in a regression to explain investment. In their models, firms are quantity constrained, so capacity utilization is a proxy for the shadow profitability of investment. A quantity-constrained firm with low utilization has little incentive to add capacity.

[7]Shapiro (1984) gives more detailed consideration of a related model but where capital is utilized at a constant rate given labor input.

[8] I estimate the required rate of return with the after-tax, real return on three-month Treasury bills plus a constant risk premium of two percent per quarter. I calculate the premium by taking a weighted average of the return in excess of the return on Treasury bills of the stock market and of corporate bonds. The weight for equity is 0.8. The excess return of the stock market is 6.7 percent; the excess return of corporate bonds is 0.6. [See Ibbotson and Sinquefeld (1982, p. 15).] Therefore, the premium is about eight percent at annual rate or about two percent at quarterly rate. I use an instrumental variables procedure that allows consistent estimation even though the rate of return is uncertain and may, in general, covary with the other variables in equation (5).

[9] Use of output data makes the productivity shock observable (abstracting from the sampling error in the estimated parameters). Hence, these estimates do not become unidentified in the presence of productivity shocks as discussed by Garber and King (1983). In their paper, the shocks are unobservable. Of course, identification of this model, as with all models, depends on assumptions on the error terms. In any case, the approach in this paper of incorporating a particular productivity shock seems a substantial improvement over the standard practice of assuming that there are no shocks at all. Note that y_t is not a valid instrument because it is correlated with the current productivity shock.

[10] If shifts are omitted from the analysis, the output elasticity of hours will be substantially greater than that of production workers because the hours of workers are then in part proxying for the hours of capital.

[11]Consider rescaling the shift work equation (6e) by multiplying it by a constant. Note that the estimated coefficients for the cost of adjustment (g_{SS} , g_{KS} , and so on) are essentially zero. Hence, multiplying (6e) by a constant will simply increase a_S and w_2 by the same proportion. Suppose we wished to constrain a_S to equal the estimated a_K , which is about one-quarter. To achieve this, equation (6e) would be multiplied by about ten. In particular, the implied w_2 would be about ten times the estimated value of 0.05, that is 0.5. Hence, if we impose that the productivity of capital and shifts are the same, the implied shift premium is exactly the overtime premium. Hence, one way of understanding the low propensity to use late shifts is that the actual cost of running late shifts is substantially higher than the data seems to imply. Note, however, that this issue only effects the interpretation of the coefficients. The dynamics studied below are unchanged by the scale of equation (6e).

[12]The average values needed to carry out the linearization are $y_t = 62.5$, $K_t = 202.0$, $L_t = 13.6$, $N_t = 4.8$, $H_t = 40.2$, $S_t = 55.0$, $q_t = 0.94$, $d = 0.9825$, $s_t^L = 142.1$, $s_t^N = 1698.1$, $r_t = .98$, $p_t^K = 0.68$, $w_t = 1.75$ and $t_t^K = 0.49$. To calculate the intercept, a_0 , in the production function (2) I set it so (2) holds given the average values and the parameter estimates. I ignore technological progress so the simulations are deviations from the steady state.

[13]The simulations are carried out using a computer program written by Jeffery Zax.

[14]Hausman (1981) estimates the uncompensated wage elasticity of labor supply to be virtually nil for adult males, but substantially higher for females. Ten percent in a compromise. I assume that non-production workers are in elastic supply because the sector demands relatively few of them. Also, implicit in the simulations is that the price of capital is given except for the tax considerations.

[15]Summers studies the entire non-farm business economy which is over four times the size of manufacturing. His simulation in Table 6 (p. 37) yields results substantially similar to those in this paper in the long run, but with much slower adjustment to the steady state.

[16]This change in the capital stock is larger than Summer's (p. 109). He assumes inelastic labor supply, which could partially account for the differences. It may also be the case that my linearization breaks down for changes this large.

[17]In that I reject the overidentifying restrictions my estimates are not consistent. It is difficult to judge the consistency of estimates in Clark's tradition.

REFERENCES

Abel, A. B.: Investment and the Value of Capital. New York: Garland, 1979.

Betancourt, R. R. and C. K. Clague: Capital Utilization: A Theoretical and Empirical Analysis. Cambridge: Cambridge University Press, 1981.

Bernanke, B. S.: "The Determinants of Investment: Another Look," American Economic Review Papers and Proceedings, 73 (1983), 71-75.

Blanchard, O. J. and C. M. Kahn: "The Solution of Linear Difference Models under Rational Expectations," Econometrica, 48 (1980), 1305-1311.

Board of Governors of the Federal Reserve System: Federal Reserve Measures of Capacity and Capacity Utilization. Washington, 1978.

Bureau of Economic Analysis, U.S. Department of Commerce: Handbook of Cyclical Indicators. Washington: G.P.O., 1977.

Bureau of Labor Statistics: Area Wage Surveys: Metropolitan Areas, United States and Regional Summaries, various numbers.

Chow, G. C. and A. Lin: "Best Linear Unbiased Interpolation Distribution, and Extrapolation of Time Series by Related Series," Review of Economics and Statistics, 53 (1971), 372-375.

Clark, P. K.: "Investment in the 1970s: Theory, Performance, and Prediction," Brookings Papers on Economic Activity, No. 1 (1979), 73-113.

Eisner, R.: Factors in Business Investment, National Bureau of Economic Research General Series No. 102. Cambridge, MA: Ballinger, 1978.

Feldstein, M. S. and D. K. Foot: "The Other Half of Gross Investment: Replacement and Modernization Expenditures," Review of Economics and Statistics, 53 (1971), 49-58.

Fischer, S.: "Dynamic Inconsistency, Cooperation and Benevolent Dissembling Government," Journal of Economic Dynamics and Control, 2 (1980), 93-107.

Foss, M. F.: "The Utilization of Capital Equipment: Postwar Compared with Prewar," Survey of Current Business, 43 (1963), 8-16.

__________: Changes in the Workweek of Fixed Capital: U.S. Manufacturing, 1929 to 1976. Washington, D.C.: American Enterprise Institute, 1981.

Garber, P. M. and R. G. King: "Deep Structural Excavation? A Critique of Euler Equation Methods," National Bureau of Economic Research Technical Working Paper No. 31, Cambridge, MA, 1983.

Hansen, L. P.: "Large Sample Properties of Generalized Method of Moments Estimators," Econometrica, 50 (1982), 1029-1054.

__________ and K. S. Singleton: "Generalized Instrumental Variables Estimation of Nonlinear Rational Expectations Models," Econometrica, 50 (1982), 1269-1286.

Hausman, J. A.: "Labor Supply," in H. J. Aaron and J. A. Pechman, eds., How Taxes Affect Economic Behavior. Washington, D.C.: The Brookings Institution, 1981.

Hedges, J. N. and E. S. Sekscenski: "Workers and Late Shifts in a Changing Economy," Monthly Labor Review, 102 (1979), 14-22.

Ibbotson, R. G. and R. A. Sinquefeld: Stocks, Bonds, Bills and Inflation: The Past and the Future. Charlottesville, VA: Financial Analyst Research Foundation, 1982.

Jorgenson, D. W. and M. A. Sullivan: "Inflation and Corporate Capital Recovery," in C. R. Hulten, ed., Depreciation, Inflation, and the Taxation of Income from Capital. Washington: The Urban Institute, 1981.

Kennan, J.: "The Estimation of Partial Adjustment Models with Rational Expectations," Econometrica, 47 (1979), 1441-1455.

Marris, R.: The Economics of Capacity Utilisation: A Report on Multiple-shift Work. Cambridge: Cambridge University Press, 1964.

________: Multiple Shiftwork, National Economic Development Office Monograph 1, London: HMSO, 1970.

Maurice, M.: Shift Work: Economic Advantages and Social Cost. Geneva: International Labor Office, 1975.

Meese, R.: "Dynamic Factor Demand Schedules for Labor and Capital under Rational Expectations," Journal of Econometrics, 14 (1980), 141-158.

Mott, P. E., F. C. Mann, Q. McLoughlin, and D. P. Warwick: Shift Work: The Social, Psychological, and Physical Consequences. Ann Arbor: University of Michigan Press, 1965.

Nadiri, M. I. and S. Rosen: "Interrelated Factor Demand Functions," American Economic Review, 59 (1969), 457-471.

Pindyck, R. S. and J. J. Rotemberg: "Dynamic Factor Demands under Rational Expectations," Scandinavian Journal of Economics, 85 (1983), 223-238.

Rotemberg, J. J.: "Interpreting the Statistical Failure of Some Rational Expectations Macroeconomic Models," American Economic Review Papers and Proceedings, 74 (1984), 188-193.

Sargent, T. J.: "Estimation of Dynamic Labor Demand Schedules under Rational Expectations," Journal of Political Economy, 86 (1978), 1009-1044.

Shapiro, M. D.: "The Dynamic Demand for Capital and Labor," Cowles Foundation Discussion Paper No. 735, New Haven, CT, 1984.

Summers, L. H.: "Taxation and Corporate Investment: A q-Theory Approach," Brookings Papers on Economic Activity, No. 1 (1981), 67-127.

Taubman, P. and P. Gottschalk: "The Average Workweek of Capital in Manufacturing," Journal of the American Statistical Association, 66 (1971), 448-455.

Taubman, P. and M. Wilkinson: "User Cost, Capacity Utilization, and Investment Theory," International Economic Review, 11 (1970), 209-215.

Tatom, J. A.: "The 'Problem' of Real Wages and Productivity," Journal of Political Economy, 88 (1980), 385-394.

Winston, G. C.: "The Theory of Capital Utilization and Idleness," Journal of Economic Literature, 12 (1974), 1301-1320.

_________: The Timing of Economic Activities. Cambridge: Cambridge University Press, 1982.