MATTHEW D. SHAPIRO
University of Michigan

Macroeconomic Implications of Variation in the Workweek of Capital

IN A TYPICAL workweek, one in every four manufacturing production workers in the United States is employed at night. This fraction fluctuates sharply over the business cycle, accounting disproportionately for business cycle changes in employment. The variation in work at night amounts to over 40 percent of the cyclical changes in the employment of manufacturing production workers. While cyclical movements in shiftwork are pervasive in many manufacturing industries, there are also some nonmanufacturing industries in which such variation is important.

Changes in the number, as well as the length, of shifts affect the workweek of capital. Demonstrating the importance of the workweek of capital for studying business cycles is the main goal of this paper. In most business cycle models, the capital stock is taken as quasi-fixed. Cyclical variation in output arises from applying more or less labor to a fixed capital stock. This property of capital should lead to diminishing marginal product of labor, to countercyclical real wage and average product of labor, and potentially to capacity constraints. Keynesian students of cyclical productivity, however, have long realized the importance of variable utilization of capacity. Their models, which admit the persistent unemployment or underemployment of both capital and labor, can readily dispense with the implications of diminishing marginal product of labor. Work on equilibrium business cycles also finds

The author gratefully acknowledges support of the National Science Foundation and the Alfred P. Sloan Fellowship, the able research assistance of Charles Fleischman, and the comments of Susanto Basu, Peter Clark, Carol Corrado, John Fernald, Gary Solon, and participants at the Brookings Panel meeting. He also acknowledges Joseph Beaulieu and Joe Mattey for providing their unpublished tabulations of the workweek of capital from the Survey of Plant Capacity.

that variable capital utilization is an important feature of an empirically coherent model.[1]

Yet both the Keynesian and the equilibrium models are often vague about how capital utilization varies. Is it through line speed, work effort, or the workweek of capital? Identifying how utilization adjustment actually takes place is important, since the utilization margin is meaningful in an equilibrium model only if increasing utilization adds to marginal cost. If there were no marginal cost, utilization would always be set at the level where its marginal product is zero. This paper attempts to redress this vagueness about the utilization margin by closely examining the cyclical behavior of the workweek of capital.

The paper documents that the workweek of capital is an important margin along which manufacturing industry operates. The extent of shiftwork provides a way to measure the workweek of capital. Unlike other utilization margins, such as linespeed and work effort, shiftwork lends itself to quantification. The first goal of this paper is to provide an empirical basis for moving the study of cyclical capital utilization from the realm of the unobservable to that of readily quantifiable time series.

The workweek of capital is not, however, the only margin by which firms vary capital utilization. The second goal of this paper is to use industry-level analysis to identify those industries in which the workweek is the key margin for utilization and those industries in which other margins (for example, line speed) are operative. Moreover, the workweek of capital is an *operative* margin because there is a cost associated with it. I show elsewhere that there is at least a 25 percent shift premium associated with employing workers at night.[2]

The paper addresses these issues in several steps, starting from a strictly empirical consideration of the workweek of capital and progressing to a more structural analysis of its role in explaining cyclical movements in total factor productivity. The next section considers how the workweek of capital enters the production function. The following

1. The role of lengthening the workweek in explaining cyclical productivity was made explicit in the seminal paper of Lucas (1970); see also Sargent and Wallace (1974). For the role of the utilization margin in equilibrium business cycle models, see Kydland and Prescott (1988), Greenwood, Hercowitz, and Huffman (1988), and Bils and Cho (1994).

2. Shapiro (1996).

section discusses how to measure the workweek of capital, focusing specifically on three distinct sources of data on shiftwork in the United States. The next section examines the extent to which variation in the workweek of capital accounts for cyclical variation in production, as measured by the Federal Reserve Board's rates of capacity utilization. In addition, it presents calculations that show what fraction of cyclical employment variation involves workers joining or leaving late shifts. The following section discusses the role of shiftwork in explaining the cyclical behavior of measured total productivity. The paper then offers some suggestions for improving the measurement of the workweek of capital.

Capital Utilization and the Production Function

The workweek of capital is meant to provide a measure of capital services. While the physical stock of capital, K, is quasi-fixed and slow to adjust, capital services might be highly variable. Consider the following five-factor gross output production function, which forms the basis of the productivity analysis presented below:

$$Y = F(Z, N, L, E, M), \tag{1}$$

where Y is gross output, Z is the services of capital, N is nonproduction labor, L is production labor, E is energy, and M is materials. The level of technology is left implicit in the production function, so the function F, as well as the inputs and outputs, is time varying. In most analyses of production functions such as F, capital services, Z, are taken to be proportional to the physical stock of capital, K. This yields the more conventional production function

$$Y = F(K, N, L, E, M). \tag{2}$$

But, as the discussion above makes clear, the conventional production function can be seriously misleading when there is variation in capital utilization. In particular, an increase in the utilization of capital will increase the level of output, even if the levels of physical capital and the other inputs are held constant. This increase in output might look like an increase in productivity, but it should be understood to arise from a mismeasurement of capital. To make this logic concrete, note that the production function, F, can be modified to represent output per hour of production. If the production process operates for S hours, total output over this period, Y, will be given by

$$Y = SF\left(K, \frac{N}{S}, \frac{L}{S}, \frac{E}{S}, \frac{M}{S}\right), \tag{3}$$

where the factors of production other than capital are divided by S because since F is per unit time, the flow of inputs must also be measured per unit time. For example, if S doubles as a result of moving from one-shift to two-shift operation, the production function must take into account the fact that the firm hires more labor and purchases more materials and energy.[3] Assuming that F is homothetic, S can be brought inside the function to yield the more familiar

$$Y = F(SK, N, L, E, M) = F(Z, N, L, E, M), \tag{4}$$

where capital services are measured as $Z = SK$, the number of capital hours. Hence this measure of capital services is analogous to the standard measurement of labor input as total hours (average weekly hours times the number of workers).

It is a mistake to use a production function such as equation 2 when a substantial fraction of the variation in output arises from variation in the workweek of capital, S. The key point is that to extend the workweek of capital, it is necessary to hire other factors. To the extent that movements in these inputs are associated with an increase in capital services, the other inputs will appear to have excess marginal products, unless capital services are correctly measured.

While variable capital utilization is usually considered to induce the mismeasurement of capital, equation 3 makes clear that it can also be thought of as inducing mismeasurement of labor (and other inputs). An increase in labor that opens a shift should have a higher marginal product than the same increase in labor applied to an existing shift. Ignoring the interaction of changes in labor with the workweek of capital seriously biases the analysis of production.

As discussed above, however, the workweek of capital is not the

3. Whether nonproduction labor should be treated as a fixed stock, analogous to capital and therefore not divided by S, is an open question. Some light is shed on this question below, in the examination of cyclical productivity.

only margin by which capital utilization can be adjusted. There can be other unobserved or difficult to observe changes in the use of factors. For example, the speed of an automobile assembly line and the amount of crude oil processed by a refinery per minute are margins of adjustment, given a fixed stock of capital and workers.[4] Although the quantities of labor and capital (but perhaps not labor effort) remain fixed when linespeed is varied, the use of materials and energy is not fixed. This consideration leads various authors to suggest using either materials or energy as a proxy for the utilization of capital, and also perhaps for labor.[5] Susanto Basu advocates the use of materials as a proxy for utilization; Dale Jorgenson and Zvi Griliches, and more recently, Craig Burnside, Martin Eichenbaum, and Sergio Rebelo advocate the use of energy.[6] Their analyses are complicated by the dual role played by both materials and energy. Each factor plays a direct role in production and also is meant to capture the utilization of other factors. This dual role can be accounted for by adding structure to the production function, F. For example, Basu assumes that value added and materials are weakly separable, with value added a function of unobserved utilization. By specifying the elasticity of substitution between materials and value added, he is able to make the unobserved input variation drop out of the measurement equation. Burnside, Eichenbaum, and Rebelo make similar assumptions of functional form with respect to energy. In both analyses the power of the proxy comes from a low elasticity of substitution with value added. The analysis of the cyclicality of total factor productivity in this paper is designed to evaluate the explanatory power of these proxy measures in light of the direct observations of capital utilization derived from the workweek of capital.

Measuring the Workweek of Capital

This section discusses various measures of the workweek of capital, S. The goal is a measure that, when multiplied by capital stock, K, will

4. On the automobile assembly line, see Bresnahan and Ramey (1993, 1994).

5. See Abbott, Griliches, and Hausman (1987) for a discussion and demonstration of the role that unobserved changes play in cyclical productivity.

6. Basu (1996); Burnside, Eichenbaum, and Rebelo (1995); Jorgenson and Griliches (1967).

be a good measure of capital services, Z. Variation in the workweek of capital can arise from three margins. First, the number of shifts that capital operates can change. Second, the number of hours in each shift can vary. Third, the number of days per week that the plant operates can change.

The Census Bureau's Survey of Plant Capacity (SPC) provides one such direct measure of capital hours. The SPC, conducted since 1974 on a subset of the firms included in the Census Bureau's Annual Survey of Manufacturers (ASM), asks how many hours per day and days per week establishments operate. While it is the best source on the workweek of capital, it does have shortcomings, as discussed below.

To extend the time period and the range of industries studied, I also use data from the Area Wage Survey (AWS) and the Current Population Survey (CPS), both conducted by the Bureau of Labor Statistics, to measure the workweek of capital on the basis of the fraction of production workers on late shifts.

The measures of the workweek of capital constructed using these three data sources all share the assumption—also implicit in this paper so far—that employment per shift is constant within a plant. Later in the paper I suggest that new data might be collected in order to relax this assumption.

Survey of Plant Capacity

In the Survey of Plant Capacity, plants are asked to report when they operate, specifically, hours per day and days per week. The product of these figures yields a direct measure of the workweek of capital. Hence the SPC provides a measure of S that maps precisely onto the production function framework outlined above.[7]

There are several limitations to the SPC data. First, the annual time series is available for only a short sample period.[8] Second, the data refer only to the fourth quarter. And third, the survey records only total

7. Currently, the main use of the SPC is as a source of information for the Federal Reserve Board's measure of capacity utilization. The role of SPC-based measures of "preferred" and "practical" output in the utilization statistics is discussed below. The workweek of capital is not currently an ingredient of the capacity utilization statistics.

8. Foss (1963, 1981, 1984) studies long-term trends in capital utilization using similar surveys for various years. Unfortunately, these historical data are not frequent enough to provide insight into the cyclical nature of shiftwork.

employment, not employment per shift. Despite these limitations, the SPC is quite useful for studying capital utilization. The short sample includes the major recession of the early 1980s, a significant episode for the study of cyclical productivity. Moreover, if data are only to be available for a single quarter, the fourth quarter is a reasonable choice because it is aligned with end-of-year capital stocks and is typically a period of high, but not peak, production.[9]

There are difficulties in aggregating the SPC measures of plant hours.[10] To construct its published and unpublished industry aggregates, the Census Bureau weights the plant-level data by total production employment. This procedure is problematic because those plants that operate more shifts will have a larger total of workers and will therefore be overweighted.[11] The problem becomes worse when the number of shifts varies over time. Factories that add a shift have their weights increase when their workweeks lengthen and therefore are double-counted.

Elsewhere, I address the problem of aggregation by correcting the census tabulations to account for the potential heterogeneity in shifts per day across plants.[12] This correction implicitly assumes that operative shifts have a constant ratio of capital to labor. Joseph Beaulieu and Joe Mattey also consider the weighting problem. To obtain aggregates at the level of the four-digit standard industrial classification (SIC), they weight by employment per shift. To aggregate the four-digit industries, they weight by industry-level measures of the real capital stock.[13] The present paper makes use of Beaulieu and Mattey's unpublished SPC series.

9. The seasonal peak in overall production occurs in the third quarter (Miron, 1994).

10. Aggregation can be dispensed with by using the plant-level data that the Census Bureau's Center for Economic Study merges with the Longitudinal Research Database of firms from the ASM/Census of Manufacturing. Such micro-level data are used by Mattey and Strongin (1995), Beaulieu and Mattey (1996), and Beaulieu and Shapiro (1995). These data must be aggregated, however, if the SPC is to be used as an indicator of the business cycle.

11. Consider two plants with the same capital stock and the same employment per shift. If one plant works eight hours per day and the other works twenty-four hours per day, weighting by total employment yields an average workweek of twenty hours. In fact, the average workweek of capital is sixteen hours.

12. Shapiro (1993).

13. Beaulieu and Mattey (1996). They also present a tabulation in which plant-level observations are weighted by the book value of the capital stock. Using employment per

Area Wage Survey

The capital-based measure from the SPC provides a direct measure of capital hours based on the number of hours that plants operate. By contrast, the labor-based measures estimate the workweek of capital, S, from the fraction of workers on shift, according to the formula

$$S = H(\lambda_1 + 2\lambda_2 + 3\lambda_3), \quad (5)$$

where H is the average workweek of labor and λ_1, λ_2, and λ_3 are the fraction of workers in plants operating one, two, and three shifts, respectively.[14] The labor-based data on shiftwork provide the number of workers on each of the three shifts—L_1, L_2, and L_3. Following Paul Taubman and Peter Gottschalk, the fractions of workers in plants operating one, two, and three shifts can be calculated by assuming that for every late shift there is an early shift of equal size.[15] Hence $\lambda_1 = (L_1 - L_2)/L_1$, $\lambda_2 = (L_2 - L_3)/L_1$, and $\lambda_3 = L_3/L_1$. Thus the labor-based measures share two assumptions with the capital-based measure: that the capital intensities of shifts are equal both within and across plants.

The Area Wage Survey contains periodic information on the fraction of workers on late shifts in various U.S. cities. Taubman and Gottschalk use the AWS to construct a workweek of capital series for manufacturing. Elsewhere, I use an extended version of the Taubman-Gottschalk data to study the role of capital utilization in the demand for physical capital.[16]

Since the AWS is based on a rolling sample of areas, some of the variability in its measure of the workweek arises from the specific characteristics of the areas that are sampled in a given time period, such as the mix of industries. Joram Mayshar and Gary Solon conduct a fresh analysis of the AWS data on shiftwork to control for these problems.[17]

shift assumes that capital intensity is equal across plants and also across shifts within plants. Using the capital stock relaxes the first assumption, while retaining the second. Hence the capital stock (preferably corrected for inflation) is a conceptually superior measure; but the data are available only for a shorter period. At least for the aggregate, Beaulieu and Mattey find that the cyclical patterns of capital hours are quite similar for the two measures, weighted by capital and employment per shift.

14. Thus, unlike the SPC-based measures of the workweek, the labor-based measures ignore variation in work on the weekend.

15. Taubman and Gottschalk (1971).

16. Taubman and Gottschalk (1971); Shapiro (1986).

17. Mayshar and Solon (1993).

In particular, they estimate a factor model to extract the aggregate component of shift employment, while controlling for the city-specific effects. Their work provides the most up-to-date analysis of the AWS data—in terms of both its econometric techniques and the period of time that it covers. The empirical analysis in this paper uses the Mayshar-Solon version of the AWS series on the fraction of workers on late shifts.[18]

The measure of S based on equation 5 makes use of labor hours as well as the fraction of workers in plants with one, two, or three shifts. In general, I allow the workweek of labor, H, to vary over time. However, I also present results based on holding the workweek of labor fixed at its average, $\overline{H}$, that is,

$$S' = \overline{H}\,(\lambda_1 + 2\lambda_2 + 3\lambda_3). \tag{6}$$

This measure understates the true variation in the workweek of capital because an increase in H, holding shifts constant, should increase S, but S' allows the effects of changing shifts and changing labor hours to be separated.

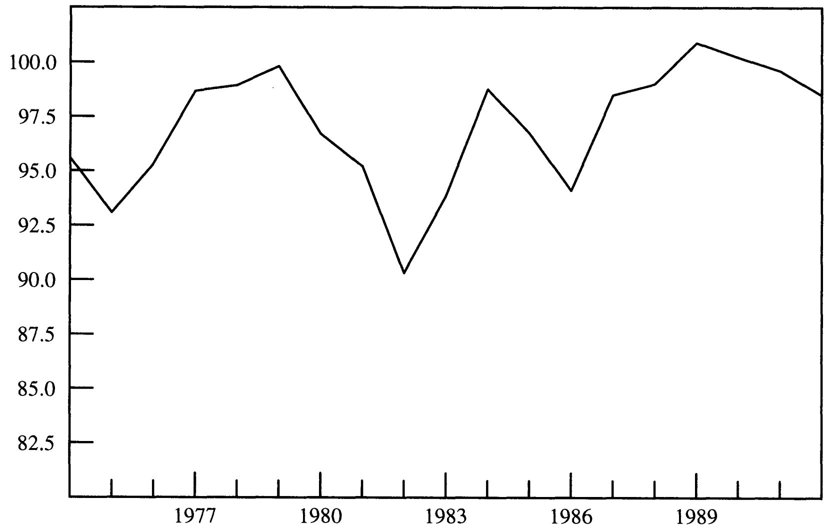
Current Population Survey

The final source of shiftwork data that I consider is the Current Population Survey. The May supplements to the CPS in 1973–81, 1985, and 1991 contain questions about work schedules. Specifically, workers are asked the hours at which they start and end work. From their responses, one can calculate the fraction of workers on each of the three shifts (λ_1, λ_2, and λ_3) and use equations 5 and 6 to construct S and S'. These data have the advantage of being based on a representative sample of the U.S. population. Also, unlike the other measures of shiftwork, the CPS data are not limited to manufacturing. To form industry-level aggregates, I sum the number of workers per shift in each industry, using the CPS sampling weights.

18. The Industry Wage Survey (IWS) reports fractions of total workers on second and third shifts for a rolling cross-section of industries, in contrast to the AWS's rolling cross-section of cities. Although this time-varying industry structure makes the IWS less suitable than the AWS for constructing an aggregate time series, the IWS is very useful for cross-sectional studies of shiftwork; see Shapiro (1996).

Figure 1. Workweek of Capital Based on Survey of Plant Capacity, 1974–92

Hours per week



Source: Data set underlying Beaulieu and Mattey (1996).

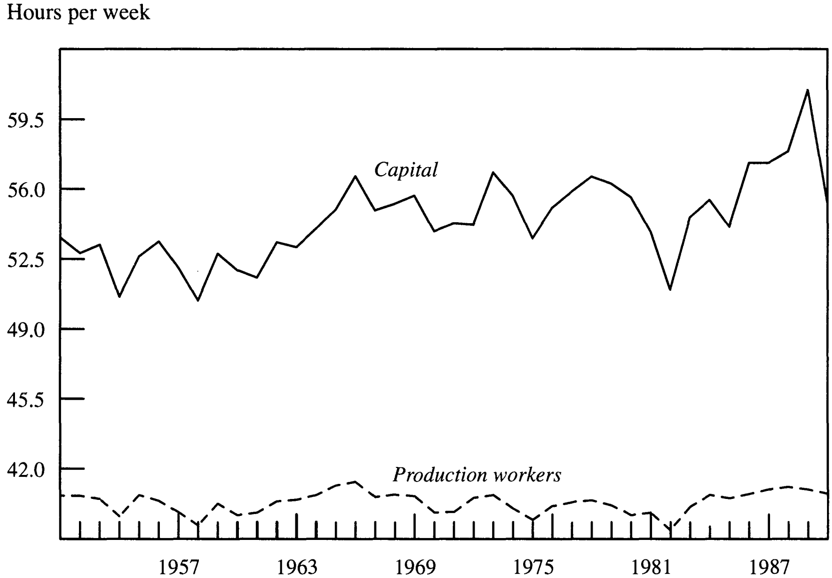
Comparing the Measures

Figures 1, 2, and 3 report time-series plots of the various measures of the workweek of capital for the aggregate data. Tables 1 and 2 report summary statistics. As noted above, the series cover different time periods and different periods within the year.[19] From the SPC, the average workweek of capital in U.S. manufacturing is 97.0 hours per week. It has a statistically significant upward trend of 0.2 hours per week per year over the period 1974 through 1992.[20] The workweek of

19. The SPC data are for the fourth quarter, from 1974 through 1992; the AWS data are annual, from 1951 through 1990; and the CPS data are for May, from 1973 through 1991 (excluding 1982–84 and 1986–90). Throughout this paper, the empirical work takes account of the fact that the various measures of the workweek of capital refer to different periods of the year. The SPC is matched with fourth-quarter data, the AWS with annual data, and the CPS with May data. It is important to use the appropriate period within the year for two reasons. First, the workweek might have a seasonal component. Second, for the short time-series sample, the timing of peaks and troughs within the year can affect the results.

20. This trend continues the long-term growth in night work that Foss (1981, 1984) highlights.

Figure 2. Workweek of Capital Based on Area Wage Survey and the Workweek of Labor, 1951–90

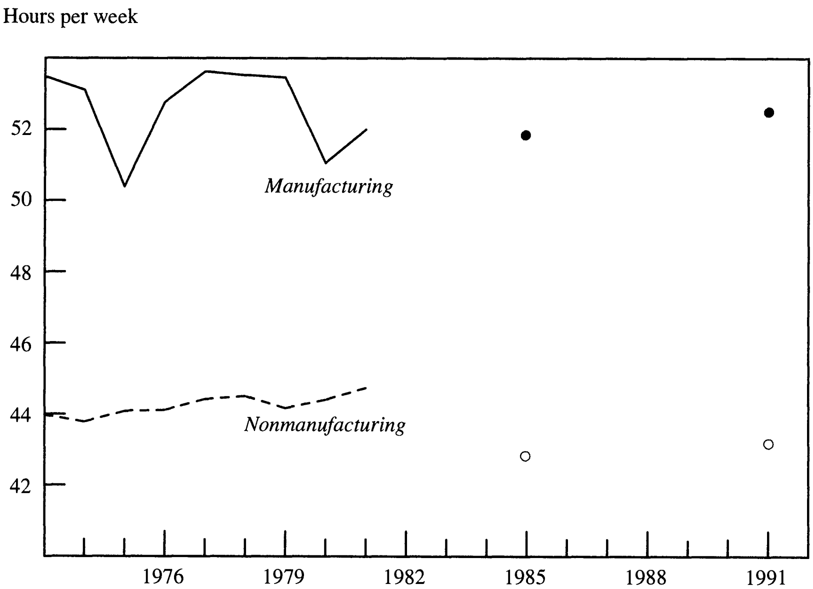


Source: Author's calculations. Late shift employment shares used to calculate the capital workweek are from Mayshar and Solon (1993). Labor workweek data, which are presented directly and are also used to calculate the capital workweek, are from Bureau of Labor Statistics, *Employment and Earnings*, various issues.

capital is highly variable: more than twice as variable relative to its mean as the workweek of labor. The dips in capital hours around 1975, 1981, and 1991 correspond to recessions; the peaks correspond to the booms at the end of the 1970s and the end of the 1980s (see figure 1). The correlations between the workweeks of capital and labor are strong, although by no means perfect.

The Mayshar-Solon measure of the workweek of capital from the AWS is available for a longer period than is the SPC measure. It is more variable relative to its mean than the SPC measure. It also has a significant drift over time that adds about four hours to the workweek of capital over the sample, in contrast to the flat workweek of labor. Again, the peaks and troughs of the workweek correspond to the business cycle (see figure 2). The AWS workweek is strongly correlated with the workweek of labor, but about half of that correlation is accounted for by the use of labor hours data to scale the shiftwork fractions.

Figure 3. Workweek of Capital Based on Current Population Survey, Manufacturing and Nonmanufacturing Industries, 1973–91[a]



Source: Author's calculations. Late shift employment shares are from Bureau of Labor Statistics, Current Population Survey (May supplement), various surveys. Labor workweek data are from Bureau of Labor Statistics, *Employment and Earnings*, various issues.

a. Data not available for 1982–84 and 1986–90.

The CPS data allow the calculation of capital workweeks in both manufacturing and nonmanufacturing industries. For manufacturing, the CPS measure is somewhat lower and less variable than the AWS measure.[21] It has noticeable troughs in the recession years of 1975 and 1980, but not in 1991. The nonmanufacturing workweek is substantially lower, less variable, and less correlated with the business cycle than is the workweek in manufacturing. This aggregation hides some interesting heterogeneity within nonmanufacturing industry that is discussed below.

21. The AWS is based on a representative sample of establishments, while the CPS is based on a representative sample of workers. The night workers in the CPS probably work in larger than average establishments, but there are no data available with which to correct this selection bias.

Table 1. Measures of the Workweeks of Capital and Labor
Hours per week

Workweek measure	*Sample period*[a]	Workweek: *Mean*	*Standard deviation*[b]	*Trend*[c]
Capital, manufacturing				
Survey of Plant Capacity	1974–92	97.0	2.6	0.2
Area Wage Survey	1951–90	54.5	1.6	0.1
Current Population Survey	1973–91[d]	52.5	1.1	. . .
Capital, nonmanufacturing				
Current Population Survey	1973–91[d]	44.0	0.6	. . .
Labor, manufacturing[e]	1951–90	40.4	0.5	. . .

Source: Data for the Survey of Plant Capacity (SPC) workweek are from the data set underlying Beaulieu and Mattey (1996). Late shift employment shares used to calculate the Area Wage Survey (AWS) workweek are from Mayshar and Solon (1993). Late shift employment shares used to calculate the Current Population Survey (CPS) workweek are from the Bureau of Labor Statistics, Current Population Survey (May supplement), various surveys. Labor workweek data, which are presented directly in the table and also are used to calculate the AWS and CPS workweeks, are from Bureau of Labor Statistics, *Employment and Earnings*, various issues.

a. Observations from the SPC are for the fourth quarter. Observations from the AWS and those of labor hours are annual averages. Observations from the CPS are for May.

b. For detrended data, where applicable.

c. Hours per week per year (reported only when statistically significant).

d. Excludes 1982–84 and 1986–90.

e. Manufacturing production workers.

The Workweek of Capital and Cyclical Fluctuations in Production and Employment

How important are cyclical changes in the workweek of capital for production and employment? This section explores this question, first, by relating cyclical movements in the workweek of capital to the Federal Reserve Board's measure of capacity utilization. It then examines what fraction of the fluctuations in production employment over the cycle is accounted for by workers moving on and off late shifts.

The Workweek of Capital and Capacity Utilization

The Federal Reserve Board's capacity utilization rate provides a convenient, detrended source of data on production. Capacity utilization is the ratio of production to a smooth measure of capacity output.[22]

22. Hence the Federal Reserve Board's capacity utilization rate is not a direct measure of capital utilization; see Shapiro (1989). A further discussion of utilization statistics is presented below.

Table 2. Correlations among Workweek Measures, Manufacturing[a]
Correlation coefficients

	Capital			
	Survey of Plant Capacity	*Area Wage Survey*	*Current Population Survey*	*Labor*[b]
Capital				
Survey of Plant Capacity	1.0	0.67	0.82	0.38
Area Wage Survey		1.0	0.74	0.75
Current Population Survey			1.0	0.87
Labor[b]				1.0

Source: Author's calculations. For sources of workweek data, see table 1.
a. Correlations are calculated over period for which both correlated measures are available; for sample periods, see table 1.
b. Manufacturing production workers.

AGGREGATE MANUFACTURING. Table 3 reports the simple correlation between each of the three measures of the workweek and the Federal Reserve Board's capacity utilization rate. The SPC and AWS workweeks are detrended; capacity utilization has no trend.

Table 3 shows that the workweek of capital is strongly procyclical. The SPC-based measure has a correlation coefficient of 0.84 with capacity utilization. The AWS-based measure is almost as cyclical. Even using the S' measure with hours of labor fixed at their average, the correlation is high. In the sample period that overlaps with that of the SPC, the AWS measure remains highly cyclical, but a smaller fraction of its correlation with capacity utilization is accounted for by variation in the workweek of labor. The CPS-based measure is also shown to be strongly procylical, despite its deviations from the standard business cycle chronology exhibited in figure 3. The last two lines of table 3 report the cyclicality of the workweek of labor, as measured by the average weekly hours series of the Bureau of Labor Statistics.

BY INDUSTRY. To understand the differences across industries in the use of the capacity utilization margin is an important aim of this paper. Table 4 presents summary statistics for the SPC-based measure of the workweek of capital and its correlation with the Federal Reserve Board's capacity utilization rate in the two-digit manufacturing industries. Table 5 takes a step beyond examining this simple correlation; it compares the explanatory power for capacity utilization of the workweek of capital with that of total weekly production worker hours.

Table 3. Correlations between Workweek Measures and Capacity Utilization, Manufacturing

Workweek measure[a]	*Labor workweek (variable or fixed)*[b]	*Sample period*	*Correlation with capacity utilization*[c]
Survey of Plant Capacity		1974–92	0.84
Area Wage Survey	variable	1951–90	0.75
	fixed	1951–90	0.55
	variable	1974–90	0.73
	fixed	1974–90	0.61
Current Population Survey	variable	1973–91[d]	0.85
	fixed	1973–91[d]	0.73
Labor[e]		1951–92	0.74
		1974–90	0.63

Source: For sources of workweek data, see table 1. Capacity utilization is measured by the Board of Governors of the Federal Reserve System, release G.17, "Industrial Production and Capacity Utilization" (hereafter, release G.17).

a. Data from the SPC and the AWS are detrended; other data have no trend.

b. Labor workweek is denoted by H in equation 5. "Variable" indicates that H is allowed to vary with time when the capital workweek is calculated from the AWS and CPS measures, and "fixed" indicates that H is fixed at its mean for the sample period.

c. Correlation coefficient.

d. Excludes 1982–84 and 1986–90.

e. Manufacturing production workers.

Specifically, it shows the results of a bivariate regression of capacity utilization on the workweek of capital and total production worker hours.

The first three columns of table 4 report the mean workweek of capital by the SPC measure, its standard deviation, and its trend. Industries vary greatly on how intensively they use their physical capital. Low capital-intensive piece-work industries (for example, apparel, furniture, and leather) operate few late shifts. At the other extreme, highly capital-intensive process industries (for example, paper, chemicals, petroleum, stone, clay, glass, and primary metals) operate during most of the available hours. Between these extremes are the durable goods assembly industries (for example, transportation equipment and machinery) and the relatively capital-intensive, but noncontinuous process, nondurable industries (for example, food and tobacco). Moreover, the industries with an intermediate mean tend to have a higher standard deviation. That is, they use the workweek of capital margin more intensively.

Table 6 reports analogous results for the CPS data. Figure 4 plots the mean SPC workweek shown in table 4 against the mean CPS manufacturing workweek shown in table 6. For relatively small values of

Table 4. Workweek of Capital Based on Survey of Plant Capacity, by Manufacturing Industry, 1974–92

Hours per week, except as indicated

Industry	*Mean*	*Standard deviation*	*Trend*[a]	*Correlation with capacity utilization*[b]
Food	83.9	7.0	1.2	0.43
Tobacco	89.3	12.0	1.6	. . .
Textiles	108.8	9.5	1.4	0.47
Apparel	44.6	2.0	0.3	0.10
Lumber	54.0	4.2	0.5	0.44
Furniture	50.2	2.1	0.2	0.30
Paper	138.1	6.5	. . .	0.43
Printing	71.9	4.1	0.5	0.57
Chemicals	132.1	3.6	. . .	0.26
Petroleum	156.8	3.0	. . .	0.06
Rubber	102.2	6.3	. . .	0.58
Leather	48.3	6.0	0.6	0.43
Stone, clay, and glass	104.0	4.7	0.6	0.38
Primary metals	125.3	10.5	. . .	0.78
Fabricated metals	69.8	5.4	0.7	0.56
Nonelectrical machinery	69.0	4.3	. . .	0.85
Electrical machinery	74.4	7.2	1.1	0.25
Transportation equipment	73.6	6.2	0.7	0.77
Instruments	63.2	4.2	. . .	0.25
Miscellaneous	59.1	6.0	0.9	0.08

Source: Author's calculations based on capital workweek data from the data set underlying Beaulieu and Mattey (1996) and capacity utilization data from the Board of Governors of the Federal Reserve System, release G.17.

a. Hours per week per year (reported only when statistically significant).

b. Correlation coefficient. Capacity utilization data for tobacco are not available.

the workweek, the relationship between the two is linear. For CPS workweeks of over eighty hours, it flattens out, suggesting that in these high-capital utilization industries, late shifts are lightly staffed. Put differently, there is a substantial fixed labor force, even of production workers, that works during the day, especially for the high-utilization industries.

The last columns of tables 4 and 6 report the results of industry-by-industry correlations of capacity utilization and the workweek of capital.[23] These results show that the workweek of capital explains capacity utilization well in some industries but poorly in others. For example, shiftwork is strongly correlated with capacity utilization in nonelectrical

23. Mattey and Strongin (1995, table 1) present similar calculations for total manufacturing and groups of industries based on the micro-level data from the SPC.

Table 5. Explaining Capacity Utilization with the Workweek of Capital and Total Labor Hours[a]

Industry	*Independent variable[b]* *Workweek of capital[c]*	*Independent variable[b]* *Labor hours[d]*	*R^2 by independent variable(s)* *Workweek of capital only*	*R^2 by independent variable(s)* *Labor hours only*	*R^2 by independent variable(s)* *Both workweek of capital and labor hours*
All manufacturing	0.79 (0.24)	0.22 (0.10)	0.70	0.52	0.77
Food	−0.04 (0.11)	0.24 (0.08)	0.16	0.45	0.45
Textiles	0.29 (0.27)	0.32 (0.26)	0.26	0.28	0.33
Apparel	−0.31 (0.26)	0.81 (0.24)	0.01	0.38	0.43
Lumber	−0.07 (0.22)	0.72 (0.14)	0.21	0.71	0.71
Furniture	−0.07 (0.14)	0.57 (0.06)	0.10	0.87	0.87
Paper	0.28 (0.12)	0.44 (0.20)	0.18	0.15	0.37
Printing	0.36 (0.21)	0.41 (0.20)	0.33	0.37	0.47
Chemicals	0.28 (0.27)	0.54 (0.21)	0.07	0.30	0.35
Petroleum	−0.24 (0.77)	−0.38 (0.26)	0.00	0.11	0.12
Rubber	0.25 (0.14)	0.53 (0.14)	0.33	0.57	0.64
Leather	0.14 (0.09)	0.39 (0.14)	0.20	0.39	0.46
Stone, clay, and glass	−0.00 (0.15)	0.74 (0.07)	0.15	0.88	0.88
Primary metals	0.21 (0.38)	0.69 (0.30)	0.61	0.70	0.70
Fabricated metals	0.01 (0.14)	0.61 (0.11)	0.35	0.78	0.78
Nonelectrical machinery	0.79 (0.20)	0.18 (0.14)	0.72	0.48	0.74
Electrical machinery	0.23 (0.21)	0.65 (0.08)	0.09	0.86	0.87
Transportation equipment	0.31 (0.18)	0.44 (0.15)	0.61	0.70	0.75
Instruments	0.03 (0.36)	0.35 (0.28)	0.06	0.23	0.23
Miscellaneous	−0.19 (0.11)	0.63 (0.12)	0.01	0.59	0.65

Source: Author's regression, as described in text. Data on the capital workweek, based on the SPC, are from the data set underlying Beaulieu and Mattey (1996). Data on labor hours are from Bureau of Labor Statistics, *Employment and Earnings*, various issues. Capacity utilization is measured by the Board of Governors of the Federal Reserve System, release G.17.

a. The dependent variable is capacity utilization. The capital workweek is the SPC-based measure. The sample period is 1974–92. A time trend is included when statistically significant. Standard errors are shown in parentheses.

b. Coefficients are for the regression using both independent variables.

c. Natural log of hours per week.

d. Natural log of total manufacturing production worker hours.

Table 6. Workweek of Capital Based on the Current Population Survey, by Industry, 1973–91[a]

Hours per week, except as indicated

Industry	*Mean*	*Standard deviation*	*Trend[b]*	*Correlation with capacity utilization[c]*
All Mining	58.8	3.1	. . .	0.47
Metal	63.2	5.8	−0.7	0.35
Coal	71.5	9.7	. . .	0.55
Petroleum	51.3	2.3	. . .	0.23
Nonmetallic	53.6	4.2	. . .	0.08
Food	57.2	3.5	. . .	0.25
Tobacco	65.4	10.3	. . .	. . .
Textiles	63.0	4.2	. . .	0.63
Apparel	37.2	0.8	0.1	0.37
Lumber	46.7	1.6	−0.2	0.56
Furniture	42.9	1.6	0.2	0.76
Paper	65.3	3.3	. . .	0.10
Printing	51.9	2.3	. . .	0.11
Chemicals	57.1	2.1	. . .	0.37
Petroleum	57.9	3.9	. . .	0.02
Rubber	65.1	2.7	. . .	0.26
Leather	39.9	1.6	. . .	0.20
Stone, clay, and glass	54.6	2.3	−0.3	0.30
Primary metals	62.3	3.2	. . .	0.48
Fabricated metals	52.3	1.4	. . .	0.85
Nonelectrical machinery	52.2	1.8	−0.2	0.59
Electrical machinery	51.0	1.3	. . .	0.23
Motor vehicles	64.0	5.2	. . .	0.89
Other transportation equipment	53.3	2.8	. . .	0.42
Instruments	49.4	1.7	. . .	0.01
Miscellaneous	45.1	1.5	. . .	0.39

Source: Author's calculations based on late shift employment data from Bureau of Labor Statistics, Current Population Survey (May supplement), various surveys; labor workweek data from Bureau of Labor Statistics, *Employment and Earnings*, various issues; and capacity utilization data from Board of Governors of the Federal Reserve System, release G.17.

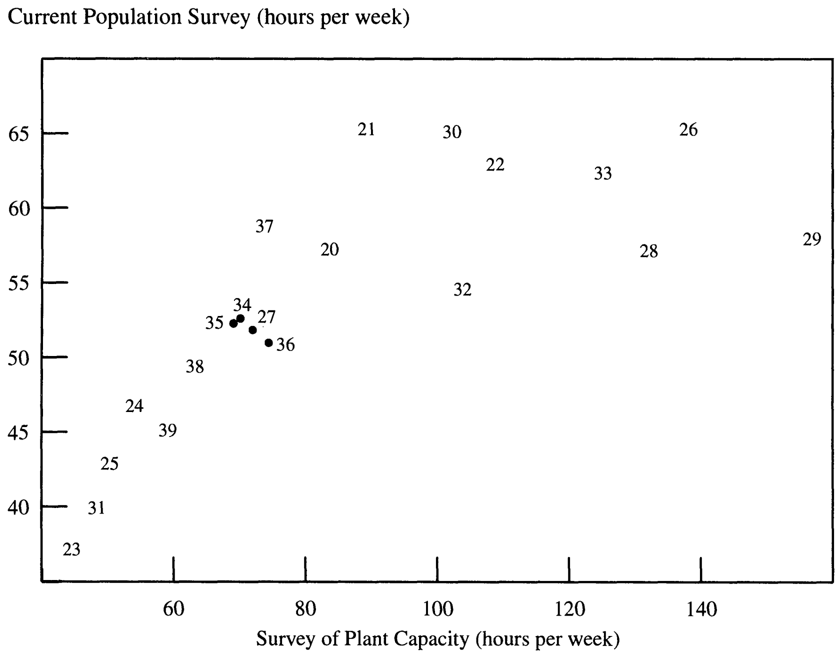
a. Sample period excludes 1982–84 and 1986–90. Calculated using equation 5 and assuming a variable labor workweek, H.

b. Hours per week per year (reported only when statistically significant).

c. Correlation coefficient. Capacity utilization data for tobacco are not available.

machinery, transportation equipment, and primary metals, and also in fabricated metals, rubber, and printing. Other industries in which shiftwork is cyclical are textiles and lumber. Industries in which shiftwork is not correlated with capacity utilization are those in which late shifts are uncommon (for example, apparel and furniture) or operations are continuous (for example, chemicals and petroleum).

Figure 4. Comparing Workweek of Capital Measures, Two-Digit Manufacturing Industries[a]



Source: Data for the SPC workweek are from the data set underlying Beaulieu and Mattey (1996). The CPS workweek is the author's calculation based on late shift employment data from Bureau of Labor Statistics, Current Population Survey (May supplement), various surveys; and labor workweek data from Bureau of Labor Statistics, *Employment and Earnings*, various issues.

a. Industries are identified by their two-digit standard industrial classification. The sample period for the CPS is 1974–91, excluding 1982–84 and 1986–90; and for the SPC, is 1974–92.

The CPS data tell a similar but somewhat weaker story. Since there are only eleven observations in these tabulations, the results are subject to high sampling variation. The CPS data also allow examination of the mining component of capacity utilization. The workweek of capital is cyclical in mining production. This correlation essentially derives from coal mining, where the workweek of capital is highly variable.

Returning to the SPC data, table 5 reports the results of regressing capacity utilization on the natural log of the workweek of capital and of total weekly production worker hours. The aim of this exercise is to understand more clearly which industries make use of the workweek of capital margin, controlling for total labor hours. The first two columns report the semielasticities of utilization with respect to the capital workweek and total labor hours.[24] The last column gives the R^2 of the bivariate regression. The table also includes the R^2 from univariate regressions, so that incremental explanatory powers can be assessed.

Given that capacity utilization is constructed to measure the cyclical component of production, the regression coefficients can be interpreted as the elasticity of cyclical production with respect to the explanatory variables. For aggregate manufacturing, both the workweek of capital and total weekly production worker hours play an important role in explaining variation in production. The workweek of capital has the larger coefficient and the greater univariate explanatory power. Hence the workweek of capital is not merely a cyclical indicator, but one that dominates production worker hours in explaining total manufacturing production.

The industry-level results show that after controlling for overall employment, the workweek of capital remains a powerful explanatory variable for production in nonelectrical machinery and transportation equipment. It is also significant, both statistically and economically, in paper and rubber. In some industries (textiles, printing, and primary metals) the workweek and labor are jointly significant, but highly collinear. This collinearity is not surprising. Indeed, if all changes in employment involved changes in shift, hours of labor and the workweek of capital would move closely together. In a few industries (notably, food and fabricated metals) the high explanatory power of the workweek for production that is evidenced in table 4 disappears once variation in total labor hours is taken into account. Finally, in the industries that exhibit low correlations in table 4, elasticities are small and the workweek has low explanatory power in table 5.

The Cyclicality of Shift Employment

To what extent is variation in total employment accounted for by workers coming on and off late shifts? Tables 7 and 8 show the share of workers on late shifts and the sensitivity of late shift employment to changes in total employment. Table 7 gives the results for production

24. The regressions include trends when they are warranted.

Table 7. Regressing Late Shift Employment on Total Employment, Manufacturing Production Workers[a]

	Share of workers on late shifts				
Industry	*Mean*	*Standard deviation*	*Trend*[b]	*Regression coefficient*[c]	R^2
All manufacturing, Area Wage Survey	0.26	0.02	0.01	1.62†	0.88
All manufacturing, Current Population Survey	0.24	0.01	...	1.48†	0.79
Noncontinuous process	0.23	0.01	−0.00	1.59†	0.83
Continuous process	0.33	0.02	−0.01	0.63	0.75
Food	0.30	0.04	0.02	0.49	−0.02
Tobacco	0.40	0.10	0.03	0.87	0.29
Textiles	0.36	0.04	−0.01	1.38*	0.79
Apparel	0.04	0.01	−0.00	−0.45	−0.08
Lumber	0.16	0.03	−0.02	1.14	0.26
Furniture	0.09	0.03	0.03	2.96†	0.62
Paper	0.35	0.03	−0.00	1.06	0.35
Printing	0.28	0.03	0.01	0.59	0.12
Chemicals	0.27	0.03	−0.01	0.84	0.21
Petroleum	0.26	0.05	0.01	2.28†	0.59
Rubber	0.37	0.03	−0.01	1.04	0.76
Leather	0.07	0.03	...	0.36	0.01
Stone, clay, and glass	0.24	0.03	−0.02	2.08*	0.38
Primary metals	0.34	0.03	−0.01	1.37	0.69
Fabricated metals	0.22	0.02	−0.00	1.54†	0.82
Nonelectrical machinery	0.20	0.02	−0.02	1.62*	0.49
Electrical machinery	0.21	0.02	−0.00	0.94	0.48
Motor vehicles	0.35	0.04	−0.01	1.63†	0.89
Other transportation equipment	0.23	0.03	−0.01	1.81†	0.61
Instruments	0.19	0.03	−0.01	1.13†	0.69
Miscellaneous manufacturing	0.14	0.03	0.01	0.84	0.01

Source: Author's regressions, as described in text. Data on late shift employment are from Mayshar and Solon (1993), for the AWS; and Bureau of Labor Statistics, Current Population Survey (May supplement), various surveys. Total employment data are from Bureau of Labor Statistics, *Employment and Earnings*, various issues.

a. The dependent variable is the natural log of late shift employment of manufacturing production workers. The independent variable is the natural log of total employment of manufacturing production workers. The sample period is 1951–90 for the regression using AWS data, and 1973–90 (excluding 1982–84 and 1986–90) for regressions using CPS data.

b. Change in share per year (reported only when statistically significant).

c. * indicates statistically different from one at the 10 percent level; † indicates statistically different from one at the 5 percent level. Tests are based on autocorrelation-consistent standard errors.

Table 8. Regressing Late Shift Employment on Total Employment, Nonmanufacturing Workers[a]

	Share of workers on late shifts				
Industry	*Mean*	*Standard deviation*	*Trend[b]*	*Regression coefficient[c]*	$\bar{R}^2$
Agriculture	0.11	0.02	0.01	1.26	0.63
Metal mining	0.26	0.06	−0.01	1.75†	0.96
Coal mining	0.34	0.08	...	1.72†	0.84
Petroleum extraction	0.10	0.03	−0.03	0.96	0.55
Nonmetallic mining	0.16	0.06	...	1.17	−0.02
Construction	0.03	0.00	...	0.43	0.48
Trucking and warehousing	0.24	0.02	0.02	0.86	0.82
Other transportation	0.23	0.02	...	0.43	0.25
Communications and utilities	0.10	0.01	−0.01	0.51	0.45
Wholesale trade	0.07	0.01	0.01	0.86	0.64
Retail trade excluding restaurants	0.22	0.01	0.01	0.84	0.91
Restaurants	0.50	0.03	−0.01	0.80	0.96
Finance, insurance, and real estate	0.28	0.01	0.03	0.78	0.91
Personal services	0.27	0.07	−0.05	0.81	−0.01
Other private services	0.12	0.01	0.00	0.75	0.97
Government	0.15	0.01	0.00	1.21†	0.84

Source: Author's regressions, as described in text. Data on late shift employment are from Bureau of Labor Statistics, Current Population Survey (May supplement), various surveys. Total employment data are from Bureau of Labor Statistics, *Employment and Earnings*, various issues.

a. The dependent variable is the natural log of late shift employment of nonmanufacturing workers. The independent variable is the natural log of total employment of nonmanufacturing workers. The sample period is 1973–91, excluding 1982–84 and 1986–90.

b. Change in share per year (reported only when statistically significant).

c. † indicates statistically different from one at the 5 percent level. Tests are based on autocorrelation-consistent standard errors.

workers in manufacturing, while table 8 gives the results for all workers in nonmanufacturing industries.[25]

If the fraction of workers on late shifts were constant over the cycle, then the elasticity of employment on late shifts with respect to total employment would be unity. For the AWS sample from 1951 though 1990, the elasticity is estimated to be 1.62—both economically and statistically significantly greater than one.[26] Given the share of employ-

25. The dichotomy between production workers and nonproduction workers is not obviously useful outside manufacturing.

26. This elasticity of 1.62 is close to the excess sensitivity of late shift employment to GNP of 1.86 that Mayshar and Solon (1993) estimate. Their estimate effectively uses the growth rate in aggregate output as an instrumental variable for the growth rate in overall employment. That their estimate is higher implies a negative correlation between employment and the error term, such as would arise if employment growth were measured with error.

ment, this elasticity implies that 42 percent of changes in employment occur on late shifts. A similar result holds for the shorter sample from the CPS.

The third and fourth rows of table 7 present results according to whether the workers are employed in a continuous process industry. In a continuous process industry, the technology requires operations around the clock, so the workweek of capital margin is not operative.[27] Table 7 shows that the continuous process industries are relatively shift intensive, but that the shiftwork is acyclical. The noncontinuous process industries have a substantially higher fraction of employment variation on late shifts, despite their lower shift intensity.

The two-digit detail reveals substantial excess sensitivity of late shift employment to total employment in transportation equipment, fabricated metals, and nonelectrical machinery—just the capital-intensive assembly industries in which one would expect shiftwork to be an important margin. Yet there are also some surprises. Furniture has the highest elasticity, but a low share. Petroleum and stone, clay, and glass also have high elasticities. In this short sample, however, the years of the OPEC price shocks have high leverage. The results for these energy-intensive industries might well be anomalies driven by changes in the composition of plants.

Table 8 presents analogous results for nonmanufacturing industries. Metal and coal mining show substantial excess sensitivity of late shift employment to total employment. The absence of late work in construction—cyclical or otherwise—is perhaps a surprise. Apparently daylight is a factor of production. In services, although many workers are on late shifts, shiftwork exhibits little cyclical sensitivity. To the extent that services are specific to the time of day or require the participation of the consumer, there may be little scope for producing during daily slack periods in the use of capital.

Hence the data show—at least for a subset of manufacturing and mining industries—that a substantial fraction of variation in total employment arises from workers being added to or subtracted from late shifts. This finding has important implications for the understanding of

27. I follow Foss (1984, p. 40) in applying this distinction to the study of shiftwork. My tabulations use his classification of continuous process industries: pulp, paper, and paperboard (SIC 261-63), chemicals (SIC 28, except 283-85, 89), petroleum (SIC 29), and primary metals (SIC 331, 333).

cyclical productivity. If adding a worker means also adding the services of capital that was previously idle at night, then there is no presumption of diminishing marginal product of labor.

The Workweek of Capital and Cyclical Productivity

Research by Robert Hall brought the attention of macroeconomists back to cyclical productivity. He interprets the cyclicality of productivity as evidence of market power and, potentially, increasing returns. Moreover, the research program in equilibrium business cycles spawned by the work of Finn Kydland and Edward Prescott takes shocks to technology as the driving force of the business cycle.[28]

In both the empirical literature on increasing returns and the literature on equilibrium business cycles there has been increasing attention to changes in factor utilization as a source of cyclical productivity. As discussed at the outset of this paper, variable utilization might account for the observed cyclicality of productivity without increasing returns or cyclical fluctuations in technology.

This section demonstrates that this theoretical possibility is empirically valid. Indeed, observed variation in the workweek of capital can *fully* account for the cyclicality of productivity in U.S. manufacturing over the period studied. This research thus identifies capital hours as the operative margin for adjusting capital utilization in most of manufacturing industry.

In an unpublished paper, Thomas Abbott, Zvi Griliches, and Jerry Hausman show that there is a hierarchy of variables explaining cyclical productivity: energy and materials are the most flexible, production hours are intermediate, and capital and nonproduction labor have the traditional zero or negative weights in an empirical production function.[29] They explain this phenomenon in terms of an unobserved factor, U. I show here that—outside of continuous process industries—this U is S, the workweek of capital. Other authors have made different corrections to the productivity calculation to account for cyclical productivity. Basu advocates the use of materials as the utilization indicator.[30]

28. Hall (1988, 1990); Kydland and Prescott (1982).
29. Abbott, Griliches, and Hausman (1987).
30. Basu (1996).

Burnside, Eichenbaum, and Rebelo, pursuing an idea developed by Jorgenson and Griliches, use energy consumption as a proxy.[31] I will contrast the results based on the use of the workweek of capital as a utilization adjustment with those based on energy and materials.

This section presents two sets of results that build on the framework developed above. First, the utilization correction is applied exclusively to physical capital. That is, I consider various capital utilization adjustments, U, in the production function $F(UK, N, L, E, M)$. This yields several versions of a Solow residual adjusted by capital utilization. Second, I consider the possibility that the utilization adjustment should not simply multiply the capital stock. Such a possibility could arise, for example, if nonproduction labor did not need to be increased when the workweek of capital was extended (in which case, N would not be divided by S in equation 3). The possibility could also arise if ''utilization'' impinged on other factors (for example, through variation in the effort of production labor). Finally, it could arise if the utilization proxies were not supposed to get exactly capital's share in the total factor productivity calculation (that is, if there were some elasticity of substitution).

Accounting for Cyclical Productivity

Consider the production function of equation 2 with fixed utilization. The standard Solow total factor productivity residual, ϵ, is given by

$$\epsilon = \Delta y - \Delta x, \tag{7}$$

where Δy is the log change in gross output and

$$\Delta x = \alpha_K \Delta k + \alpha_N \Delta n + \alpha_L \Delta l + \alpha_E \Delta e + \alpha_M \Delta m \tag{8}$$

is the share-weighted log change in the inputs.[32] The shares, α_K, α_N, α_L, α_E, and α_M, are time varying. Robert Solow shows that under the

31. Burnside, Eichenbaum, and Rebelo (1995); Jorgenson and Griliches (1967). The idea that energy is a proxy for capital services is very old. In the absence of any data on physical capital, Flux (1913, p. 567) uses horsepower per employee as a measure of capital intensity. (I am grateful to S. J. Prais for this reference.) Moreover, the idea underlies the Federal Reserve Board's use of kilowatt hours to measure production in many industries for which physical production data are unavailable.

32. Note that while capital letters represent levels of variables, I use lower case letters to represent the natural logs of levels.

assumptions of constant returns to scale, perfect competition, and correct measurement of the factors and shares, the residual, ϵ, equals the rate of technological change, ϵ^*.[33] Observed Solow residuals are highly procyclical. An obvious source of this procyclicality is unaccounted variation in the inputs. Production might rise because factor utilization increases. If the increase in factor utilization is not reflected in total factor input, measured ϵ will be spuriously procyclical.

Therefore total factor input should be adjusted for changes in utilization, to the extent possible. Adjusting capital for its utilization is hardly a new idea. Indeed, Solow adjusts the capital stock by the unemployment rate of labor. This section follows his example by adjusting the productivity residual for directly observed changes in capital utilization, namely, the workweek of capital. It also compares adjustments based on the use of materials and energy as proxies for utilization.

Specifically, consider a gross output production function

$$Y = F(UK, N, L, E, M). \tag{9}$$

It is analogous to equation 4, except that capital utilization, U, may be measured either by the workweek of capital, energy, materials, or a composite of energy and materials. Total factor input growth, Δx, should thus additionally contain the term $\alpha_K \Delta u$, where Δu is the growth rate of utilization. Hence true technological change, ϵ^*, can be calculated as an adjusted Solow residual, $\tilde{\epsilon}$; that is,

$$\tilde{\epsilon} \equiv \epsilon - \alpha_K \Delta u = \epsilon^*. \tag{10}$$

My strategy here is to consider the success of various measures of Δu as adjustments to the Solow residual.

Before turning to the cyclical productivity regressions, I present some simple correlations in which the Federal Reserve Board's capacity utilization rate is again used as a cyclical indicator. Table 9 shows the correlations among the input growth rates, each weighted by capital's share.[34] Capital growth is largely acyclical.[35] The growth rates of the

33. Solow (1957).

34. The data on output, inputs, and production shares come from the National Bureau of Economic Research's (NBER) Productivity Database. The sample is a pool of the 450 industries included in the ASM, excluding those for which over half of the observations on the workweek of capital are missing. The sample period is limited to 1977–88, the period for which I could match the industries in the SPC data and NBER ASM data.

35. Even if Δk were constant, $\alpha_K \Delta k$ could be procyclical if capital's share increased during booms; that is, when physical capital was scarce.

Table 9. Correlations among Capacity Utilization Growth and Measures of Input Growth[a]
Correlation coefficients

	Δcu	$\alpha_K \Delta k$	$\alpha_K \Delta s$	$\alpha_K \Delta e$	$\alpha_K \Delta m$	$\alpha_K \dfrac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$
Δcu	1.00	−0.03	0.15	0.13	0.31	0.31
$\alpha_K \Delta k$		1.00	−0.01	0.15	0.13	0.13
$\alpha_K \Delta s$			1.00	0.05	0.12	0.12
$\alpha_K \Delta e$				1.00	0.37	0.45
$\alpha_K \Delta m$					1.00	0.99
$\alpha_K \dfrac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$						1.00

Source: Author's calculations based on capacity utilization data from Board of Governors of the Federal Reserve System, release G.17; inputs and production share data from the National Bureau of Economic Research's (NBER) Productivity Database; and capital workweek data from the data set underlying Beaulieu and Mattey (1996).

a. The sample comprises the 450 industries included in the Census Bureau's Annual Survey of Manufacturers (ASM), excluding those for which over half of the observations on the workweek of capital are missing. The sample period is 1977–88. The symbols Δcu, Δk, Δs, Δe, and Δm represent log changes in capacity utilization, the capital stock, the workweek of capital, energy use, and material's use, respectively; α_K, α_E, and α_M represent the production shares of capital, energy, and materials, respectively. See text for details.

other inputs are positively correlated with the cycle, but less strongly than might be expected. Moreover, the input growth rates are only weakly correlated with each other, except for materials with the energy and materials composite, which is dominated by materials.

Table 10 shows a key result. The unadjusted Solow residual, ϵ, is procyclical. When it is adjusted by subtracting the utilization adjustments, the procyclicality disappears. Adjustment by the workweek of capital makes the correlation close to zero, adjustment by energy reduces it substantially, and adjustment by materials or the composite makes it negative. Hence the correlations show the importance of a utilization correction, but they do not point strongly to any one adjustment factor. The regressions that follow are more decisive.

Cyclical Productivity Regressions

The current state of the art for quantifying the cyclicality of Solow's productivity residual is to estimate an equation

$$\epsilon = \beta \Delta x + v, \tag{11}$$

so that if β is zero, the measured productivity residual, ϵ, is an unbiased

Table 10. Correlations among Measures of Capacity Utilization Growth and Productivity Residuals[a]

Correlation coefficients

	Δcu	ϵ	$\epsilon - \alpha_K \Delta s$	$\epsilon - \alpha_K \Delta e$	$\epsilon - \alpha_K \Delta m$	$\epsilon - \alpha_K \frac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$
Δcu	1.00	0.15	0.03	0.06	−0.02	−0.02
ϵ		1.00	0.78	0.81	0.85	0.85
$\epsilon - \alpha_K \Delta s$			1.00	0.65	0.70	0.70
$\epsilon - \alpha_K \Delta e$				1.00	0.79	0.82
$\epsilon - \alpha_K \Delta m$					1.00	1.00
$\epsilon - \alpha_K \frac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$						1.00

Source: Author's calculations based on capacity utilization data from Board of Governors of the Federal Reserve System, release G.17; inputs, output, and production share data from the NBER Productivity Database; and capital workweek data from the data set underlying Beaulieu and Mattey (1996).

a. The sample comprises the 450 industries included in the Census Bureau's Annual Survey of Manufacturers, excluding those for which over half of the observations on the capital workweek are missing. The sample period is 1977–88. The symbols Δcu, Δk, Δs, Δe, and Δm represent log changes in capacity utilization, the workweek of capital, energy use, and material's use, respectively; α_K, α_E, and α_M represent the production shares of capital, energy, and materials, respectively; and ϵ, the unadjusted Solow productivity residual, is equal to Δy - Δx. See text for details.

estimate of the true growth rate of technology, ϵ^*.[36] If capital services are proportional not to the stock of capital, K, but rather to UK, where U is capital utilization, then equation 11 has an added component in the error term. That is,

$$v = \alpha_K \Delta u + \epsilon^*. \tag{12}$$

Under the presumption that Δu is positively correlated with other factors, β will be estimated to be greater than zero. To eliminate this source of cyclical productivity, I consider various adjusted Solow residuals, where Δu, instead of being omitted, is measured by the growth in the workweek of capital (Δs), energy consumption (Δe), materials use (Δm), and a share-weighted average of energy consumption and materials use. If variable capital utilization is an important source of cyclicality in measured total factor productivity, estimating

$$\tilde{\epsilon} = \beta \Delta x + v \tag{13}$$

should yield estimates of β closer to zero than estimates from equation 11.

Total factor input is correlated with true technological change, ϵ^*. Therefore, in order to yield consistent estimates, estimation is by two-stage least squares, with time dummies as instruments. The use of time dummies as instruments is based on the assumption of no aggregate productivity shock during the sample period.[37]

The first column of table 11 reports the results for all manufacturing.[38] The first row reports the estimate of β based on equation 11, using the unadjusted residual as the dependent variable and leaving the unobserved $\alpha_K \Delta u$ in the disturbance. The null hypothesis of no cyclical productivity is decisively rejected; the point estimate of 0.31 is large

36. The equation is estimated in this form rather than, for example, with Δy on the right-hand side, because there is less correlation between true productivity and input than true productivity and output. A constant to capture the trend in productivity is included in these equations, but it is suppressed in the notation and tabulation of results.

37. Note that the estimation is carried in a short sample that is dominated by the recession of 1982. In this sample, the first-stage fit of potential aggregate demand instruments (for example, party of the president) will be inadequate. On the other hand, the importance of the Volcker disinflation in this short sample makes plausible the assumption that aggregate demand disturbances do dominate the data.

38. These estimates build on those reported in Shapiro (1993). Estimation with fixed industry effects (that is, a different constant for each industry) yields similar results.

Table 11. Regressing Unadjusted and Adjusted Solow Residuals on Total Factor Input Growth[a]

	Coefficient of Δx, by industry type		
Dependent variable	*All manufacturing*	*Noncontinuous process*	*Continuous process*
ϵ	0.31 (0.04)	0.28 (0.04)	0.37 (0.08)
$\epsilon - \alpha_K \Delta s$	0.06 (0.05)	0.02 (0.05)	0.24 (0.08)
$\epsilon - \alpha_K \Delta e$	0.11 (0.05)	0.09 (0.05)	0.12 (0.08)
$\epsilon - \alpha_K \Delta m$	−0.09 (0.04)	−0.13 (0.04)	0.04 (0.08)
$\epsilon - \alpha_K \frac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$	0.08 (0.04)	−0.11 (0.04)	0.03 (0.08)

Source: Author's regressions, as described in text. Data on inputs, output, and production shares are from the NBER Productivity Database. Data on the capital workweek are from the data set underlying Beaulieu and Mattey (1996).

a. The equations estimated here regress the dependent variables shown on total factor input growth, Δx. Each equation is estimated for each of the three industry types shown. The first regression, which uses the unadjusted Solow residual as the dependent variable, is an estimate of equation 11 in the text; the remaining regressions, which use adjusted Solow residuals as dependent variables, are estimates of equation 13. Estimation is by two-stage least squares, using time dummies as instruments. Heteroskedasticity-consistent standard errors are in parentheses. The sample comprises the 450 industries included in the ASM, excluding those for which over half of the observations on the workweek of capital are missing. The sample period is 1977–88.

and is precisely estimated.[39] The other lines of table 11 consider the cyclicality of the various adjusted productivity residuals; that is, different versions of equation 13. When the workweek of capital is used as the measure of capital utilization, the cyclicality of productivity largely disappears. The coefficient falls from 0.31 to 0.06; it is insignificantly different from zero, with a fairly tight confidence interval. Hence, when Solow residuals are adjusted by the SPC-based measure of the workweek of capital, the cyclicality of productivity in U.S. manufacturing disappears.

The last three rows of table 11 show the results obtained when energy and materials are used as proxies for utilization. They account almost as well as the workweek of capital for cyclical productivity. The estimated coefficients are fairly close to zero and only marginally statistically significant.

39. This is a larger estimate of β than is found in most other work that uses the same specification. Basu and Fernald (forthcoming) find an estimate of about 0.1, but that is based on a longer sample period, beginning in 1959, which has less cyclical productivity on average.

Based on the results for total manufacturing given in table 11, one would conclude that the workweek of capital was the best way to adjust the Solow residual, but that energy and materials also were fairly good proxies for capital utilization. In some industries, however, shiftwork should not be a good indicator of capital utilization. Specifically, in the continuous process industries that require around-the-clock operation, the workweek of capital is not an operative margin. In these industries, however, materials use and energy consumption are likely to be good proxies for the rate of plant operation. The second and third columns of table 11 therefore present estimation results for the noncontinuous and continuous process industries separately.

The second column of table 11 shows that the workweek of capital does an extremely good job of adjusting the productivity residual for the noncontinuous process industries. With the workweek correction, the coefficient of Δx falls from 0.28 to 0.02. The energy and materials proxies are less well suited for accounting for the cyclicality of productivity.

On the other hand, the third column of table 11 shows that the workweek of capital does little to account for cyclical productivity in the continuous process industries. For these industries, adjustment of capital services by materials (but not energy) yields acyclical productivity residuals.

That adjustment by the workweek of capital eliminates the cyclicality of productivity in the noncontinuous process industries but fails to do so in the continuous process industries shows, importantly, that the workweek of capital is not merely a proxy cyclical indicator. The workweek of capital is a genuine measure of capital services.

Should the Utilization Adjustment Apply Only to Capital?

The regressions in table 11 constrain the utilization measure to have the same production share as the capital stock. This assumption is relaxed in tables 12, 13, and 14, which present estimates of the equation

$$\epsilon = \beta\Delta x + \gamma\alpha_K\Delta u + v. \tag{14}$$

By relaxing the restriction that γ is equal to one, estimates of equation 14 can evaluate the various utilization adjustments in a setting where they are not adjusting the capital stock in particular. As

Table 12. Regressing the Unadjusted Solow Residual on Alternative Cyclical Measures, All Manufacturing Industries[a]

Independent variable					
Δx	$\alpha_K \Delta s$	$\alpha_K \Delta e$	$\alpha_K \Delta m$	$\alpha_K \frac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$	*p value*[b]
0.31 (0.04)	...	...	...	...	...
−0.03 (0.11)	1.35 (0.38)	...	...	...	0.40
0.32 (0.05)	...	−0.06 (0.13)	...	...	0.00
−0.04 (0.12)	1.68 (0.46)	−0.36 (0.23)	...	...	0.00
0.42 (0.21)	...	...	−0.29 (0.50)	...	0.00
0.54 (0.22)	...	...	...	−0.59 (0.54)	0.00

Source: See table 11.

a. The dependent variable is the unadjusted Solow residual, ϵ. The equations estimated here regress ϵ on the independent variables shown. Relating these to equation 14 in the text, the coefficients of Δx correspond to β, the coefficient of total factor input growth, and the others correspond to γ, the coefficient of the selected capital share–weighted utilization adjustment, $\alpha_K \Delta u$. Estimation is by two-stage least squares, using time dummies as instruments. Heteroskedasticity-consistent standard errors are in parentheses. The sample comprises the 450 industries included in the ASM, excluding those for which over half of the observations on the workweek of capital are missing. The sample period is 1977–88.

b. For the chi-squared test of the null hypothesis that the coefficient of Δx is zero ($\beta = 0$) and the coefficient of $\alpha_K \Delta u$ is one ($\gamma = 1$). In the equation that includes both the workweek and energy utilization adjustments as independent variables, the test is of the null hypothesis that the coefficient of Δx is zero, the coefficient of $\alpha_K \Delta s$ is one, and the coefficient of $\alpha_K \Delta e$ is zero.

discussed above, it might be that other factors (for example, nonproduction labor) also need a utilization adjustment, or that the utilization adjustment should apply to all of value added. In either case, one would expect to find an estimate of γ greater than one, because applying the adjustment only to capital would give the adjustment too small a weight. In general, equation 14 relaxes the restriction in equation 13 that the utilization adjustment be applied only to capital; equation 14 instead applies the adjustment more broadly, throughout the production process.

Table 12 presents estimates of the coefficients of equation 14 for all manufacturing industries. One hypothesis of interest is that there is no cyclical productivity once U multiplies K; that is, β is equal to zero and γ is equal to one. The last column presents the p value for a chi-squared test of this null hypothesis. The estimate of γ for adjustment by the workweek of capital shown in the second row is somewhat higher

Table 13. Regressing the Unadjusted Solow Residual on Alternative Cyclical Measures, Noncontinuous Process Industries[a]

Independent variable					
Δx	$\alpha_K \Delta s$	$\alpha_K \Delta e$	$\alpha_K \Delta m$	$\alpha_K \frac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$	*p value*[b]
0.28 (0.04)	. . .	. . .	. . .	. . .	. . .
0.06 (0.10)	0.85 (0.33)	. . .	. . .	. . .	0.84
0.30 (0.05)	. . .	−0.12 (0.13)	. . .	. . .	0.00
0.05 (0.11)	1.11 (0.40)	−0.30 (0.18)	. . .	. . .	0.40
0.26 (0.23)	. . .	. . .	0.05 (0.55)	. . .	0.00
0.42 (0.24)	. . .	. . .	. . .	−0.35 (0.57)	0.00

Source: See table 11.

a. The dependent variable is the unadjusted Solow residual, ϵ. The equations estimated here regress ϵ on the independent variables shown. Relating these to equation 14 in the text, the coefficients of Δx correspond to β, the coefficient of total factor input growth, and the others correspond to γ, the coefficient of the selected capital share–weighted utilization adjustment, $\alpha_K \Delta u$. Estimation is by two-stage least squares, using time dummies as instruments. Heteroskedasticity-consistent standard errors are in parentheses. The sample comprises the 450 industries included in the ASM, excluding those for which over half of the observations on the workweek of capital are missing. The sample period is 1977–88.

b. For the chi-squared test of the null hypothesis that the coefficient of Δx is zero ($\beta = 0$) and the coefficient of $\alpha_K \Delta u$ is one ($\gamma = 1$). In the equation that includes both the workweek and energy utilization adjustments as independent variables, the test is of the null hypothesis that the coefficient of Δx is zero, the coefficient of $\alpha_K \Delta s$ is one, and the coefficient of $\alpha_K \Delta e$ is zero.

than one, although the standard error is large enough that it is not possible to reject the hypothesis that it is equal to one.[40] At the same time, there is overwhelming evidence against the hypothesis that the energy and materials proxies are strict capital utilization adjustments (third through sixth rows). The restrictions implicit in table 11 are rejected for these proxies. The fourth row of table 12 runs a horse race between the workweek and energy adjustments. The coefficient of the workweek adjustment remains close to one, but that of energy has the wrong sign. Table 13 shows similar results for the noncontinuous process industries.

The results for the continuous process industries, shown in table 14,

40. This estimate of γ greater than unity is consistent with the view that the workweek adjustment needs to be applied to other factors, especially to nonproduction labor. But the standard error is so large that it is difficult to give the estimate any specific interpretation.

Table 14. Regressing the Unadjusted Solow Residual on Alternative Cyclical Measures, Continuous Process Industries[a]

Independent variable					
Δx	$\alpha_K \Delta s$	$\alpha_K \Delta e$	$\alpha_K \Delta m$	$\alpha_K \dfrac{\alpha_E \Delta e + \alpha_M \Delta m}{\alpha_E + \alpha_M}$	p value[b]
0.37	...	...	...	...	...
(0.08)					
0.11	2.14	...	...	...	0.03
(0.15)	(0.80)				
0.45	...	−0.35	...	...	0.01
(0.15)		(0.51)			
0.28	2.32	−0.80	...	...	0.06
(0.21)	(0.89)	(0.73)			
0.89	...	...	−1.58	...	0.01
(0.31)			(0.82)		
0.71	...	...	...	−1.03	0.10
(0.34)				(0.94)	

Source: See table 11.

a. The dependent variable is the unadjusted Solow residual, ϵ. The equations estimated here regress ϵ on the independent variables shown. Relating these to equation 14 in the text, the coefficients of Δx correspond to β, the coefficient of total factor input growth, and the others correspond to γ, the coefficient of the selected capital share–weighted utilization adjustment, $\alpha_K \Delta u$. Estimation is by two-stage least squares, using time dummies as instruments. Heteroskedasticity-consistent standard errors are in parentheses. The sample comprises the 450 industries included in the ASM, excluding those for which over half of the observations on the workweek of capital are missing. The sample period is 1977–88.

b. For the chi-squared test of the null hypothesis that the coefficient of Δx is zero ($\beta = 0$) and the coefficient of $\alpha_K \Delta u$ is one ($\gamma = 1$). In the equation that includes both the workweek and energy utilization adjustments as independent variables, the test is of the null hypothesis that the coefficient of Δx is zero, the coefficient of $\alpha_K \Delta s$ is one, and the coefficient of $\alpha_K \Delta e$ is zero.

are once again quite different. In the regression including the workweek of capital adjustment (second row), the coefficient of Δx does fall substantially, but the coefficient of the adjustment itself is greater than two. Hence the workweek is picking up much cyclical productivity variation, but not as a capital utilization adjustment per se. For the energy and materials adjustments, the coefficients are estimated imprecisely and are of the wrong sign. Yet for the materials-energy composite, presented in the last row, the null hypothesis is rejected only at the 10 percent level.

In summary, when the adjustment share restrictions are relaxed, adjustment by the workweek of capital continues to work well for the noncontinuous process industries. Moreover, it operates as a strict capital utililization adjustment; that is, there is only weak evidence that it should have a weight other than capital's share. In the continuous process industries, the workweek adjustment, as expected, operates as a general utilization adjustment rather than as a strict adjustment to capital. The energy and materials proxies have the wrong point estimates, but these are very imprecise. The poor performance of the energy and materials proxies is surely due, in part, to measurement error. In particular, the proxies measure purchases, not consumption.

The Cost of Utilization

The foregoing results show that, at least for noncontinuous process industries, capital utilization need not be treated as an unobserved variable; rather, it corresponds to the workweek of capital. Rendering utilization a concrete margin that a firm faces (that is, how many shifts it should operate) has important implications for understanding its role over the cycle. For capacity utilization to be cyclical, there must be some cost to increasing utilization. Otherwise, cost-minimizing firms would always set utilization to its maximum value. Specifically, if variation in utilization came simply from the speed at which production lines operated, one would ask why this speed was not always maximal.[41]

In the case of shiftwork, there is a clear cost to increasing utilization. In other work I estimate that the premium associated with hiring an additional worker at night is at least 25 percent of the cost of hiring one to work during the day.[42] Hence in the presence of a fixed cost to running a shift, there is good reason for firms to use the opening and closing of shifts as a margin for adjustment of production.[43] As the present paper documents, this margin is indeed used intensively in many U.S. manufacturing industries.

Statistics on the Workweek of Capital: Discussion and Recommendations

The Federal Reserve Board measures capacity utilization as the ratio of industrial production to capacity. Industrial production indexes are constructed on a monthly basis from output measured in physical units,

41. One can imagine that depreciation in use might limit linespeed, but I know of no evidence that such an effect is substantial. Alternatively, it might be difficult or expensive to store output, so demand could determine production, in the short run.

42. Shapiro (1996).

43. See Mayshar and Halevy (forthcoming).

where such data are available. Where such data are not available, the production indexes are estimated from data on production worker hours or the use of electric power.[44]

Capacity is an index number for which production is the underlying unit: "The capacity indexes attempt to capture the concept of sustainable practical capacity, which is defined as the greatest level of output that a plant can maintain within the framework of a realistic work schedule, taking account of normal downtime, and assuming sufficient availability of inputs to operate the machinery and equipment in place."[45] The Federal Reserve uses a variety of data to estimate capacity. These include the engineering capacity of plants, capital stocks, and reported rates of utilization from surveys.[46] In the Survey of Plant Capacity, respondents are asked to give full production capability as a percentage increase relative to current output and to convert the percentage into a dollar amount of production.[47] The Federal Reserve uses the ratio of actual to full production reported by SPC respondents in constructing the utilization statistics. For benchmark periods, it divides this ratio into its measure of industrial production to yield the estimate of capacity.

While there are difficulties in defining capacity on the basis of a subjective measure of utilization, the SPC represents a substantial improvement over the previous surveys (conducted by McGraw-Hill and the Bureau of Economic Analysis) for several reasons. For example, the definitions of capacity output used by these surveys were considerably more vague and difficult to interpret than the SPC's definitions.[48]

44. These month-to-month estimates are benchmarked to lower-frequency data on production.

45. Board of Governors of the Federal Reserve System, release G.17, "Industrial Production and Capacity Utilization."

46. For a discussion of the capacity utilization data, see Corrado and Mattey (forthcoming).

47. See U.S. Bureau of the Census (1992). Starting with the 1990 SPC, which asked about production in both 1989:4 and 1990:4, the survey asked about actual, full, and "national emergency" production. Through 1988, the SPC asked instead about "preferred" and maximum "practical" rates of production. Although the definitions are somewhat different, based on its interpretation of the questions and some data analysis the Federal Reserve Board believes that preferred corresponds to full production, and practical corresponds to national emergency production. Corrado and Mattey (forthcoming) discuss in greater detail the use of the SPC to measure capacity.

48. See Shapiro (1989) for a discussion of the previous surveys.

In addition, the McGraw-Hill survey was conducted at the firm level. It is hard to see how a senior executive could give meaningful responses to such questions, especially for a multiplant firm with diverse lines of business. In contrast, the SPC is conducted at the establishment level and is directed to the "plant manager or engineer."[49] Finally, the SPC's conjectural question about full production is asked in the context of questions about the actual hours of operations per day, days per week, and value of production. Moreover, it asks the respondent to translate the percentage increase to full production into a dollar amount. This concreteness probably yields a more considered reply. Though the information about capacity output from the SPC represents a substantial improvement over its predecessor surveys, it remains subject to difficulties of interpretation, some of them perhaps inherent to any survey-based measure of utilization. For example, it does not make clear whether respondents expect ever to operate at full production.

The SPC's current treatment of shiftwork provides a good example of the difficulty of using a survey-based measure of utilization. In defining full production the SPC specifies, "Do not assume number of shifts and hours of plant operation under normal conditions to be higher than that attained by your plant any time in the past five years."[50] While such a specification might well be appropriate for the purpose of constructing a smooth measure of capacity, it belies the fact that idle capital at night represents substantial unused capacity.[51]

Improving the Survey of Plant Capacity

The Survey of Plant Capacity is one of the best sources of data on the workweek of capital in U.S. manufacturing, as evidenced by the substantial explanatory power for capital utilization and cyclical productivity that is displayed in this paper. Some modest changes in the design of the survey, however, might result in substantial benefits. I feel constrained by the current budgetary environment to offering suggestions that could be implemented without major increases in cost. For example, budget constraints are likely to preclude expanding the sur-

49. U.S. Bureau of the Census (1992, p. A-3).

50. U.S. Bureau of the Census (1992, p. A-4).

51. This element of the definition of full production will be changed in the 1995–96 survey. Henceforth, full production will include the possibility of adding shifts, even if they have not been operated previously.

vey, either by sampling more firms or by sampling all four quarters of the year instead of just one.

CONTINUE THE SPC ON A REGULAR BASIS. The SPC was conducted regularly for the years 1974 through 1988. For 1989, there was no regular survey. The 1990 survey asked for data on 1989 as well as 1990. Since then, the SPC has been conducted regularly, with the financial support of the Federal Reserve Board and the Department of Defense.

The SPC has now accumulated twenty years of continuous data. It is serving an important role in the Federal Reserve Board's measures of capacity utilization. Therefore it is important to maintain it, both for the continuity of the time series and for the valuable data that it will provide for the future.

COLLECT ADDITIONAL DATA. The SPC should add two new data items. First, it should collect data on employment per shift as well as the current data on aggregate employment and plant hours. Second, the survey should collect some information on the size of the capital stock. A book value of capital would be minimally useful. Better yet, the SPC records could be linked to responses from the ASM and the Census of Manufacturing to allow calculation of a constant-dollar capital stock. Adding these items would lead to a marginal increase in costs for the Census Bureau and the respondents, but the information would make the data already collected in the SPC much more useful.[52]

Information on employment per shift and on within-day variation in capital intensity is critical for producing a coherent picture of capital utilization. As the comparison of the SPC- and CPS-based measures of the workweek of capital in this paper shows, the assumption of constant capital intensity around the clock is questionable; to relax it, this information is required.[53] There are complications in collecting data on

52. Beginning with the 1989/90 survey, the SPC questionnaire was substantially simplified. Even with these changes, it would still remain significantly shorter than the form used through 1988.

53. These data would still not tell the whole story. Consider a firm reporting one hundred workers on the first shift and fifty on the second. Does this mean that at night capital intensity is twice as high, or only half the machines are operating? The former is probably the case for a refinery or an integrated assembly plant, and the latter for an apparel factory. It does not seem feasible to distinguish these two cases in the SPC, but progress can be made by using industry studies and econometric analysis of data on production, employment, shifts, and other factors.

employment per shift, owing to the various schemes of staggered hours and rotating shifts. The survey form should be flexible enough that a plant could specify the hours that the shifts operate.[54]

PUBLISH STATISTICS ON THE WORKWEEK OF CAPITAL. Currently, the Census Bureau publishes the full production and national emergency production capacity utilization rates for aggregates and four-digit industries. The data on plant hours are not published, although the bureau makes them available (at the four-digit level) to researchers.

Either the Census Bureau or the Federal Reserve Board should publish statistics on the workweek of capital. The unpublished census tabulations are weighted by total employment, giving excess weight to plants that operate multiple shifts.[55] Instead, aggregates should be weighted according to the size of the plant.

There are various ways to estimate the sizes of plants. The available data offer several sensible approaches. Plants can be weighted by employment per shift or employment per plant hour.[56] Yet this method has the shortcoming of assuming that capital intensity is equal across time, within and across plants. Hence a preferred alternative for the existing data is to weight plant hours by estimates of the capital stock. This maintains the assumption of constant capital intensity across shifts, but relaxes the assumption that capital intensity is equal across plants. Since more capital-intensive plants have an incentive to operate longer hours, the latter assumption leads to systematic errors.[57]

With the collection of the additional data suggested above, the weighting could be improved. In particular, it would be possible to weight establishments by employment on the first (or the largest) shift. Also, plant hours that are very thinly staffed should probably be completely excluded from the workweek of capital, because it is likely that the workers employed at these times are engaged in security, cleaning, stocking,

54. The May supplements to the CPS on shiftwork deal with these complications by asking respondents to specify the times at which shifts start and end.

55. See Shapiro (1993) and Beaulieu and Mattey (1996).

56. Shapiro (1993) implements an approximation to this approach to correct the four-digit tabulations of the Census Bureau. Using the microdata of the SPC, which are available at the Center for Economic Studies, this approach is implemented exactly by Beaulieu and Mattey (1996), whose tabulations are used above.

57. Beaulieu and Mattey (1996) produce estimates weighted by book value of capital. They focus on estimates weighted by a constant total employment per shift because lags in the Census of Manufacturing limit the availability of data weighted by the capital stock.

and maintenance.[58] Weighting by employment on the largest shift is most analogous to weighting by capital stock. It would be advisable to produce estimates weighted both by capital and by labor per shift, although further research is required as to how these measures might differ.

Conclusion

This paper documents that the workweek of capital is an important margin of adjustment in many U.S. manufacturing industries. Over the business cycle, close to half of the change in employment in U.S. manufacturing takes place on late shifts. In industries in which the shiftwork margin is operative, variation in the workweek of capital explains a substantial amount of the variation in production and virtually all of the cyclical movements in productivity. For these industries, there is no need to appeal to unobserved movements in factors or to attempt to explain cyclical productivity. Moreover, once variation in the workweek of capital is taken into account, little cyclical movement in productivity remains to either provide evidence for increasing returns to scale or drive real business cycle models.

The finding that there is no cyclical movement in productivity once observed variation in capital utilization is taken into account casts substantial doubt on the empirical relevance of models that take the cyclicality of the unadjusted productivity residual to represent the cyclicality of technology. It implies that the huge equilibrium business cycle literature spawned by Kydland and Prescott needs to focus on the sources of shocks other than those to aggregate technology.

Moreover, the recent work of Basu and John Fernald has done much to reduce estimates of the degree to which increasing returns are implied by cyclical productivity. This paper shows that once cyclical capital utilization is taken into account, there is no evidence of increasing returns. Therefore advocates of business cycle models that require substantial increasing returns cannot find evidence for their assumptions in observed cyclical productivity.

58. Such activities are necessary for production, but these factors of production should probably be viewed as an additional input into the day shift, rather than as a separate shift.

Finally, given the importance of the workweek of capital in business cycle fluctuations, it is crucial to obtain the best possible information about how the workweek is changing. This paper presents specific recommendations on making better use of existing official statistics and improving the survey measures of the workweek of capital.

Comments and Discussion

Carol Corrado: Shapiro's paper reconsiders results in the empirical literature on capital utilization. Shapiro employs three data sources on the workweek of capital that are neither widely known by macroeconomists nor widely used in empirical work on economic fluctuations. First, he compares the properties of the three data sources. Second, he looks at the relationship between the workweek of capital and cyclical fluctuations in production and employment. Third, he finds that variation in the workweek of capital accounts for the observed cyclicality of productivity in manufacturing. Last, he makes suggestions for improving the quality and accessibility of manufacturing workweek of capital statistics from the Survey of Plant Capacity.

His title notwithstanding, Shapiro provides little in the way of macroeconomic implications of his principal finding on cyclical productivity. However, he confronts as directly as possible the central issue of what could make the Solow residual closer to small white noise, and he indicates that the attention of both the empirical literature on increasing returns and the literature on equilibrium business cycles may have been, for a time, misdirected. That literature is now centered on changes in factor utilization as an explanation of cyclical productivity and the propagation mechanism for shocks. At present, individual papers present divergent explanations of the source of the apparent short-run increasing returns to scale and procyclicality. Some studies focus on unobserved changes in labor effort, or "labor hoarding." Others emphasize "capital hoarding," or the underutilization of capital under slack demand conditions. None, however, has focused on the issue of capital utilization with an application to the data as convincingly as does Shapiro in this study.

In an important paper published in 1993, Shapiro revises conventional productivity growth accounting to include a measure of the workweek of capital and finds evidence that increasing returns in manufacturing disappear when capital hours are taken into account.[1] The theoretical possibility that the cyclicality of conventionally measured total factor productivity results from variation in the workweek of capital that accompanies increases in other inputs was first pointed out by Robert Lucas.[2] Close students of this line of work will not be surprised by the results in this paper. Nontheless, Shapiro's cumulative results, especially when viewed in conjunction with the findings of several other recent studies, seem both more robust and more relevant for macroeconomists at this juncture than they did just three years ago.

In the study that provides the SPC-based estimates of the workweek of capital for this paper, Beaulieu and Mattey reconsider Shapiro's 1993 findings using a slightly different data set. They also find that when the capital stock is adjusted for workweek changes, to proxy for the flow of capital services, the evidence for increasing returns is weakened. Employing very different techniques, Burnside, Eichenbaum, and Rebelo take electricity use as a proxy for the flow of capital services and focus on higher frequency, quarterly changes in the data. They, too, find that total factor productivity is not very procyclical when variation in capital use is taken into account.[3]

In this study, Shapiro further demonstrates that the cyclicality of manufacturing productivity disappears once variation in capital hours is taken into account. He uses an improved data set for the workweek of capital and confirms his 1993 results, which were based on fewer data points. He also shows that the workweek adjustment dominates alternative proxies for the flow of services from capital that have been offered in the literature, such as energy use or materials use. Shapiro's results and the findings of Burnside and his coauthors reinforce and complement each other: the former, more fully specified, are based on panel data with annual observations, while the latter are derived from

1. Shapiro (1993).
2. Lucas (1970).
3. Beaulieu and Mattey (1996); Burnside, Eichenbaum, and Rebelo (1995).

quarterly data, a richer frequency for understanding business cycle dynamics.

Shapiro's results fall short in that they are not as general as he casts them. He argues that the workweek of capital is a ''genuine measure of capital services'' and uses the term interchangeably with ''capital utilization'' and ''shift work.'' He may do this with little loss of generality for an industry that has an assembly line technology, like motor vehicles, but for many other major industry groups it is inappropriate. Furthermore, Shapiro's specification assumes that all factors are spread evenly across operative shifts and that only capital has increasing returns, in the sense that no more is needed to operate additional shifts at a plant. I elaborate on these arguments to make three points.

First, the SPC figures that Shapiro uses provide information on the average weekly workperiod when the plant is open. It is the product of the number of days per week of operation and the number of plant hours per day of operation. The latter can be decomposed into shifts per day and hours per shift. The plant's work period may be expanded by adding a day on the weekend (if the plant does not normally operate seven days a week), by running a given shift for longer hours, or by adding another shift. When the work period is lengthened by adding a shift or adding hours to an existing shift, the work period adjustment in the productivity accounting will capture the returns from all quasi-fixed factors of production—notably, nonproduction workers—or any component of the production process that imposes a fixed cost per day rather than a marginal cost per shift. Shapiro's adjustment to the Solow residual accounts for variation in the plant's work period weighted by capital's share. Thus a more precise accounting would also include an adjustment of the variation in hours per day weighted by the cost share of other relevant quasi-fixed factors.

Second, the average work period of the plant is *not* conceptually equivalent to capital utilization. Moreoever, the distinction is not limited to continuous processors. Some noncontinuous process operations are organized on a piecework basis; unlike assembly lines, they operate more as a collection of workstations. These workstations may or may not be completely staffed and, as a practical matter, the plants may not tend to run extra shifts. For such an industry, labor input determines how much of a fixed capital stock is utilized over a fixed work period, and variation in labor hours will more closely approximate capital utilization than will the plant work period.

Third, Shapiro's framework for describing and modeling factor utilization and firms' adjustment margins is neither general nor complete. The related microeconomic literature emphasizes that the dynamics of aggregate economic activity are determined by the interaction of heterogenous agents who face differing costs in adjusting to aggregate demand shocks. This literature provides guidance on how to characterize factor utilization and a firm's adjustment margins. Mattey and Steve Strongin, who summarize much of that literature, follow both George Stigler, in emphasizing the technological trade-offs between flexibility and average efficiency, and Lucas, in emphasizing that adjustments in the work period of capital can be an important margin. They work with the SPC microdata and describe, not adjustment costs in manufacturing alone, but the industry distribution of adjustment cost patterns.[4]

Mattey and Strongin introduce three different technology types to summarize conveniently the apparent differences between industries. At one extreme are the continuous processors, which face large shutdown and startup costs and prefer to operate nearly twenty-four hours a day, seven days a week. Operations with this type of technology do not use the work-period margin, except under very adverse demand conditions when the plant will be shut down for weeks or months at a time. Rather, continuous processors adjust the plant's consumption of materials to achieve short-run changes in output.

At the other extreme are the pure assemblers, which routinely vary the normal work period of the plant to adjust actual output. That is, they vary the intensity of capital use—the fraction of the production period over which capital is used—to achieve short-run changes in output. The work period of capital is adjusted by increasing the duration of shifts, especially when the plant faces small or transient demand shocks, or by adding an additional shift, when it faces larger and more persistent changes. Between these extremes, the technology of other noncontinuous processors tends to be as I describe above. Many of these industries make relatively little use of the work-period margin and achieve short-run output changes along the familiar lines of ad-

4. Mattey and Strongin (1995); Stigler (1939); Lucas (1970).

justing labor relative to a fixed stock of capital that generally operates for a fixed work period. This group of industries accounts for roughly 30 percent of value added in manufacturing.

Despite these conceptual qualifications, Shapiro convincingly demonstrates the quantitative importance of understanding cyclical variation in the workweek of capital. One simple reason why the workweek of capital is so effective at reducing the Solow residual to white noise is as follows: Much of the cyclical variation in output stems from variability in the demand for final products produced by durable goods industries. For many of those goods—such as motor vehicles and a large portion of capital goods—production occurs on an assembly line, and producers routinely use the shift margin to adjust output in response to demand shocks.

I now turn to a brief discussion of Shapiro's presentation of statistical correlations between the alternative measures of the workweek of capital and the cyclical fluctuations in production and employment. As expected, the fraction of workers on late shifts in manufacturing is strongly cyclical. I approached this paper eager to learn more about the cyclical variation in the intensity of capital use in nonmanufacturing industries. Shapiro's important findings on cyclical productivity pertain only to manufacturing. Hall's earlier work, which provoked a debate in macroeconomics that Shapiro suggests has been misdirected, finds increasing returns virtually everywhere else in the economy. Eric Bartlesman argues that the evidence of large and pervasive increasing returns can be explained by bias in Hall's econometric procedure. However, a careful reading of Bartlesman's corrected evidence shows that, outside of manufacturing, significant scale economies are still found in transportation and retail trade.[5]

Clearly, employment in industries such as transportation and retail (as well as wholesale) trade is very cyclical. These industries provide distribution services for the economy's final demand for goods, which drives much of the business cycle. But Shapiro finds no evidence of cyclicality in shiftwork for these industries, despite the fact that a relatively high fraction of their work force is employed in the evening and at night. Given the shift premiums in wages, it is not plausible that workers in these industries prefer to work at night; more likely, to

5. Hall (1988, 1990); Bartelsman (1993).

maintain customer satisfaction, the industries respond to cyclical changes in demand by making production adjustments evenly over the day. If so, these industries, like those within manufacturing that Shapiro does not consider, perform capital-labor substitution similar to the simple textbook examples, and the variation in capital utilization is not captured by the workweek of capital.

Shapiro also reports that about 70 percent of the variation in aggregate manufacturing capacity utilization is accounted for by variation in the workweek of capital. I should note that 70 percent of the variation in aggregate capacity utilization is also explained by variation in overtime hours. Adding hours to an existing shift is often the first margin of adjustment in variable work-period industries. According to my own tabulations, overtime hours and the workweek of capital together explain 85 percent of the variation in capacity utilization, each contributing approximately the same amount to the goodness of the overall fit. (Shapiro finds that only 77 percent of the variation in capacity utilization is jointly explained by variation in total labor hours and the workweek of capital.) Thus Shapiro's exploration of covariability between the workweeks of capital and labor would be more complete if he also looked at the distinction between straight-time and overtime hours.

The last section of the paper discusses statistics on manufacturing capacity utilization and the workweek of capital, which are both derived from the same survey instrument—the SPC. Shapiro's discussion of the ingredients of the the Federal Reserve's statistics on capacity utilization, however, does not provide a clear sense of the Fed's approach to measuring capacity. My recent study with Mattey provides a simple summary.[6]

With regard to capacity utilization statistics from the SPC—the basic data source for the Federal Reserve's estimates—the specifics of how the survey instructs respondents to provide utilization figures have already been changed to eliminate the odd guideline on shifts that Shapiro mentions. Indeed, that guideline was imposed only during 1989–94. Furthermore, in contrast to Shapiro's conjecture that respondents have difficulties in answering the SPC's questions about capacity, the "pin" factory visits sponsored by the National Bureau of Economic Research's Project on Industrial Technology and Productivity reveal that most plant

6. Corrado and Mattey (forthcoming).

managers can be quite precise about the production capabilities of their facilities.

I support Shapiro's specific suggestions for improvements and marginal additions to the SPC. Clearly, if official figures on the workweek of capital were to be published, they should be properly weighted, and a complete picture of capital use would be possible only with information on its within-day variation.

In summary, Shapiro's work, here and elsewhere over the years, has focused its readers' attention on the quantitative role of capital utilization and shiftwork as a propagation mechanism for shocks. As a result, macroeconomists who study economic fluctuations may begin to use statistics on the workweek of capital regularly, and we should commend him for adding that to our repertoire.

Peter K. Clark: Shapiro's paper on the workweek of capital is both interesting and informative because he examines data sets that are not easily accessible and are not usually discussed in the literature. These data support the mainstream view that cyclical variations in labor productivity arise from the lagged response of factor inputs to cyclical changes in the demand for output. The first set of data that he analyzes is the workweek of capital found in the Census Bureau's Survey of Plant Capacity. The data shown in figure 1 roughly coincide with my prior beliefs: they are clearly procyclical, and the relative magnitudes of various recessions seem to be correct.

The next series that Shapiro examines is the Mayshar-Solon data from Area Wage Surveys. Once again, the procyclical nature of the workweek of capital is apparent (see figure 2). The low point in the 1980–82 recession is lower than that in 1973–75. I also notice the possibility of an upward trend in these data, starting in the late 1970s or early 1980s; the average workweek of capital may have been increasing over the past ten or twenty years. Such a secular increase in the utilization of existing capital would be interesting if it really existed. But any upward trend might instead be due to sectoral shifts in demand; or my eyeball signal extraction process could be faulty.

The final data set that Shaprio uses is the Current Population Survey. These data, plotted in figure 3, seem much inferior to the other two. For example, in 1981 the CPS, unlike the other two series, records an increase in the workweek of capital. I find this very unlikely. In 1981, all of us at the Federal Reserve Board watched in amazement as the money supply grew beyond target, the federal funds rate was raised to astronomical levels, and the economy continued to deteriorate: unemployment eventually reached rates not seen since before World War II. This anomalous rise in capital's workweek, along with the fact that observations for most of the 1980s are missing, makes me think that the CPS data are not worth analyzing.

Shapiro concludes from these data, first, that shift work is an important margin in capital-intensive assembly industries. As demand increases, existing shifts can be lengthened or new shifts added, increasing the effective amount of capital input. Labor productivity rises because the added labor is almost exclusively in production; the number of other workers in a firm stays more or less constant. The evidence on this is quite clear and indisputable. A second point that appears in the paper, although Shapiro does not discuss it directly, is that procyclical movements in labor productivity are clearly not productivity shocks falling from the sky, but instead a reaction of production to changes in output caused by variations in demand. I find it embarrassing that a larger majority of economists has not embraced this view, given the preponderance of evidence in its favor.

One final implication that Shapiro draws from his data is that variations in the capital workweek can be thought of as variations in capital input and that, once these variations are correctly accounted for, the cycle in labor productivity disappears. He makes a strong case for this view in assembly manufacturing, but assembly manufacturing accounts for about 20 percent of private sector output. In the other 80 percent, particularly services and trade, variations in individual effort are probably more important than those in shiftwork for the generation of procyclical productivity.

For example, consider a well-established restaurant in Washington, D.C. At the end of a recession, business may be a little weak, with reservations available even on Friday or Saturday night. But as economic activity in Cleveland and Orlando and Los Angeles picks up, lobbyists' expense accounts get a little fatter, corporate travel to D.C. becomes a little easier to justify, and gross receipts at the restaurant begin to rise. Employment at the restaurant stays constant, recorded hours may rise a little (but less than actual hours, particularly for management), and measured labor productivity increases substantially. The restaurant's hours of business may not have changed at all, so data on the workweek of capital would show no increase.

This story, told for the entire private business sector, has a long and successful track record. It is sometimes called a partial adjustment or an adjustment cost model; other authors have termed it labor hoarding. I have used it in two Brookings papers to explain cyclical variations in aggregate labor productivity, and it still fits the data very well.[1] The story that Shapiro tells for assembly manufacturing follows the same well-tested idea, with production labor more variable than other types of labor. Thus his results confirm the traditional lagged linkage between output and factors of production.

Two further points came to mind while I was studying the paper. First, annual data—even if they are point samples rather than annual averages—obscure the character of the business cycle. It has been my experience that quarterly data give a superior view of peaks and troughs in economic activity; accurate monthly data are slightly better yet. Shapiro's data, although they do exhibit business cycle behavior, are missing some pieces. This is not his fault (the data are collected annually or even less frequently), nor even the fault of the federal statistical agencies (who are doing a heroic job in the face of severe budget constraints). But it does mean that measurement errors may be more significant than they are in higher frequency data.

Second, can one correctly analyze both cyclical and secular movements in productivity with one simple aggregate production function? For Shapiro and many other productivity analysts recently, the answer has been yes. Hence the many and varied attempts to eliminate Solow residuals. Such an approach is intrinsically attractive. The ability to provide one explanation for many phenomena is the essence of many a scientific reputation. Newton's theory of gravity explained many things, Darwin's natural selection, many more. But while Robert Solow is justly renowned among economists, I do not think that an aggregate production function is in the same league as gravity or natural selection. For me, at least, the right way to think about the supply side of the economy is with two equations: an aggregate production function to explain the secular relation between inputs and output, and a partial

1. Clark (1984, 1993).

adjustment model to analyze deviations from trend at business cycle frequencies.

General discussion: Several panelists were surprised by Shapiro's finding that taking account of shifts could eliminate the cyclical fluctuations in measured factor productivity. Ben Bernanke noted that when a plant adds a second shift it effectively replicates the first shift and so should display constant returns with respect to labor; he found it hard to understand why the failure to account for capital services would create estimates of the elasticity of output with respect to labor far in excess of unity. N. Gregory Mankiw noted that Bernanke and Clark were both referring to labor productivity, whereas Shapiro's results related to total productivity. Carol Corrado asserted that both measures were procyclical. Christopher Sims noted that in his earlier work using data on hours by production workers, he found elasticities of output with respect to direct labor input of about one. Month-to-month random fluctuations in output did induce high-frequency productivity fluctuations, but over intervals as short as six months, these movements disappeared. William Brainard noted that Shapiro's results do not leave much room for other explanations for cyclical productivity, such as the presence of fixed, nonproduction workers suggested by Clark. If anything, economists have an embarrassment of riches to explain away increasing returns.

Robert Gordon suggested that it was helpful to distinguish different frequencies of productivity fluctuations. According to Gordon, high-frequency monthly and quarterly changes are best explained by the difficulty and cost of rapidly adjusting labor. Like Clark and Sims, Gordon has found that firms adjust labor to surprises in demand over three or four quarters. He noted it was important to recognize that at this frequency, productivity relates to the rate of growth of output, not to its level. Shapiro's analysis, using annual data, abstracts from these high-frequency changes within the year and is most useful in illuminating medium-term cyclical productivity. Long-run changes in productivity and the behavior of productivity at the end of expansion both involve different considerations.

Robert Hall was dissatisfied by the absence of a clearly specified theory of capital utilization and raised several questions that such a theory should answer. Why do firms in equilibrium have different numbers of shifts? Why is capital not used twenty-four hours a day if there is no associated deterioration? What is the cost of capital services for a firm that chooses to operate its capital stock less than full time? Gordon suggested that the pay premium needed to get workers on the night shift may be quite large. Shapiro reported that he estimated the shift premium at 25 percent, but he has no evidence that the shift premium is cyclical. Gordon suggested that one reason why capital is not run all the time in nonmanufacturing industries is the importance of "knowledge" workers. Hence the firm's operation is limited to the number of hours such individuals can work in a day.

George Perry noted the contrast between continuous process industries, which already work capital nearly continuously, so that the capital utilization margin cannot be very important, and other industries that may adjust along this margin. Although many continuous process industries are not very cyclical (with the exception of steel), they may adjust along other margins. James Duesenberry gave as an example firms bringing older plants back into utilization in times of peak demand.

Hall was surprised that the evidence from recent studies of utilization has left no room for imperfectly competitive markets or increasing returns. These results suggest that perfect competition is pervasive. Yet, with all the evidence of concentration and other industry characteristics implying imperfect competition, he argued that cannot be right. There are many elements of fixed cost—for example, intellectual property—which imply that in order for a firm to recoup its investment, it must price above marginal cost and show increasing returns. Hall observed that the profession may have been surprised and skeptical about evidence he had previously presented that increasing returns were pervasive, but now the pendulum is swinging too far in the other direction.

Mankiw noted a striking macroeconomic implication of the paper. It shows that productivity fluctuations in manufacturing are largely a passive response to the cycle rather than the driving force, as postulated in RBC-type models. If true, it suggests that shifts in demand reflecting changing policy and preferences, not shifts in technology, are responsible for short-run fluctuations. He suggested, however, that the results are not likely to extend to nonmanufacturing sectors, where shiftwork is less prevalent, and hence may not be true for the aggregate economy.

References

Abbott, Thomas A., Zvi Griliches, and Jerry A. Hausman. 1987. ''Short Run Movements in Productivity: Market Power versus Capacity Utilization.'' Unpublished paper. National Bureau of Economic Research.

Bartelsman, Eric J. 1993. ''Of Empty Boxes: Returns to Scale Revisited.'' *Economics Letters* 49(1): 59–67.

Basu, Susanto. 1996. ''Procyclical Productivity: Increasing Returns or Cyclical Utilization?'' *Quarterly Journal of Economics* 111(3): 719–51.

Basu, Susanto, and John G. Fernald. Forthcoming. ''Returns to Scale in U.S. Production: Estimates and Implications.'' *Journal of Political Economy.*

Beaulieu, J. Joseph, and Joe Mattey. 1996. ''The Workweek of Capital and Capital Utilization in Manufacturing,'' revised. Unpublished paper. Board of Governors of the Federal Reserve System (April).

Beaulieu, J. Joseph, and Matthew D. Shapiro. 1995. ''Capital Utilization, Factor Productivity, and Returns to Scale: Evidence from Plant-Level Data.'' Unpublished paper. Board of Governors of the Federal Reserve System (December).

Bils, Mark, and Jank-Ok Cho. 1994. ''Cyclical Factor Utilization.'' *Journal of Monetary Economics* 33(2): 319–54.

Bresnahan, Timothy F., and Valerie A. Ramey. 1993. ''Segment Shifts and Capacity Utilization in the U.S. Automobile Industry.'' *American Economic Review, Papers and Proceedings* 83(2): 213–18.

———. 1994. ''Output Fluctuations at the Plant Level.'' *Quarterly Journal of Economics* 109(3): 593–624.

Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo. 1995.''Capital Utilization and Returns to Scale.'' In *NBER Macroeconomics Annual 1995*, edited by Ben S. Bernanke and Julio J. Rotemberg. Cambridge, Mass: MIT Press.

Clark, Peter K. 1984. ''Productivity and Profits in the 1980s: Are They Really Improving?'' *BPEA, 1:1984*, 133–67.

———. 1993. ''Tax Incentives and Equipment Investment.'' *BPEA, 1:1993*, 317–39.

Corrado, Carol, and Joe Mattey. Forthcoming. ''Capacity Utilization.'' *Journal of Economic Perspectives.*

Flux, A. W. 1913. ''Gleanings from the Census of Production Report.'' *Journal of the Royal Statistical Society* 76(6): 557–85.

Foss, Murray F. 1963. ''The Utilization of Capital Equipment: Postwar Compared with Prewar.'' *Survey of Current Business* 43(6): 8–16.

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

———. 1984. *Changing Utilization of Fixed Capital: An Element in Long-Term Growth.* Washington: American Enterprise Institute.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W. Huffman. 1988. "Investment, Capacity Utilization, and the Real Business Cycle." *American Economic Review* 78(3): 402–17.

Hall, Robert E. 1988. "The Relation between Price and Marginal Cost in U.S. Industry." *Journal of Political Economy* 96(5): 921–47.

———. 1990. "Invariance Properties of Solow's Productivity Residual." In *Growth, Productivity, Employment*, edited by Peter Diamond. Cambridge, Mass.: MIT Press.

Jorgenson, Dale W., and Zvi Griliches. 1967. "The Explanation of Productivity Change." *Review of Economic Studies* 34(3): 249–83.

Kydland, Finn E., and Edward C. Prescott. 1982. "Time to Build and Aggregate Fluctuations." *Econometrica* 50(6): 1345–70.

———. 1988. "The Workweek of Capital and Its Cyclical Implications." *Journal of Monetary Economics* 21(2–3): 343–60.

Lucas, Robert E., Jr. 1970. "Capacity, Overtime, and Empirical Production Functions." *American Economic Review, Papers and Procedings* 60(2): 23–27.

Mattey, Joe, and Steve Strongin. 1995. "Factor Utilization and Margins for Adjusting Output: Evidence from Manufacturing Plants." Finance and Economics Discussion Series 95-12. Washington: Board of Governors of the Federal Reserve System (March).

Mayshar, Joram, and Yoram Halevy. Forthcoming. "Shiftwork." *Journal of Labor Economics.*

Mayshar, Joram, and Gary Solon. 1993. "Shift Work and the Business Cycle." *American Economic Review, Papers and Proceedings* 83(2): 224–28.

Miron, Jeffrey A. 1994. "The Economics of Seasonal Cycles." In *Advances in Econometrics: Sixth World Congress*, vol 1., edited by Christopher A. Sims. New York: Cambridge University Press.

Sargent, Thomas J., and Neil Wallace. 1974. "The Elasticity of Substitution and Cyclical Behavior of Productivity, Wages, and Labor's Share." *American Economic Review, Papers and Proceedings* 64(2): 257–63.

Shapiro, Matthew D. 1986. "Capital Accumulation and Capital Utilization: Theory and Evidence." *Journal of Applied Econometrics* 1(3): 211–34.

———. 1989. "Assessing the Federal Reserve's Measures of Capacity and Utilization." *BPEA, 1:1989*, 181–225.

———. 1993. "Cyclical Productivity and the Workweek of Capital." *American Economic Review, Papers and Proceedings* 83(2): 229–33.

———. 1996. "Capacity Utilization and the Marginal Premium for Work at Night." Unpublished paper. University of Michigan.

Solow, Robert M. 1957. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39(3): 312–20.

Stigler, George. 1939. "Production and Distribution in the Short Run." *Journal of Political Economy* 47(3): 305–27.

Taubman, Paul, and Peter Gottschalk. 1971. "The Average Workweek of Capital in Manufacturing." *Journal of the American Statistical Association* 66(335): 448–55.

U.S. Bureau of the Census. 1992. *Survey of Plant Capacity, 1990*. Washington: Department of Commerce.