CAPITAL UTILIZATION

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Utilization of capital can take place through variations in the duration of working time, given intensity, or through variations in the intensity of working time, given duration, or both. This article focuses on the economic factors determining duration and discusses the issues affecting and affected by variations in intensity. The latter can take the form of variations in speed or in the use of inputs that are complements to capital relative to some maximum or optimum. We provide a historical perspective, discuss modern theory, its main applications and links to the issues of speed and capacity, and identify important implications.

Capital utilization is given different interpretations in the economic literature. If a machine is available for use during, say, a day, then various levels of utilization can be obtained by varying the duration of operations within the day. For any fixed duration within the day, however, it is also possible to vary the machine's rate of utilization by varying its speed. In each case there is variation in capital utilization, but both physical and economic characteristics differ widely in the two cases. Moreover, even with duration and speed constant within the day, some writers define variations in capacity utilization via variations in the variable inputs employed with a given machine per day relative to some maximum or optimum daily output. Unfortunately, these as well as other writers frequently use the terms 'capital utilization' and 'capacity utilization' interchangeably.

The discussion here will focus on the analysis of variations in the duration of operations. A brief historical perspective sets the stage for a presentation of modern theory and applications, including links to the issues of speed and capacity. A succinct conclusion provides implications for closely related economic issues.

Historical perspective

Concern with the duration of operations dates to the late 18th century and the spread of the factory system in England. Early writing emphasized the appropriate length of the working day relative to its social consequence for workers and its economic consequence for capitalists. Positions on these issues were developed in the context of debates over the various Factory Acts in England. These discussions usually assumed the length of the working day to be the same for capital and labour.

Marx provides a most interesting example of the development of economic thinking on duration up to his time. The length of the working day is given substantial attention in his work (1867, ch. 10); indeed, it provides the cornerstone for his theory of exploitation (see, for example, Morishima, 1973, ch. 5); yet Marx pays only minor attention to the separation of capital's work day from labour's work day which is at the centre of modern analysis.

Marshall, like his predecessors, was interested in duration because of its implications for the well-being of workers and the viability of the economic system. But he saw the separation of the work day of labour from the work day of capital inherent in shift-work systems as an opportunity for resolving the conflicting interests of workers and capitalists with respect to the length of the work day. Thus he becomes an advocate of the adoption of multiple shifts early in his professional career (1873) and maintained his interest in the topic throughout his career (see, for example, 1923, p. 650).

Marshall's emphasis became the basis for the work of Robin Marris (1964), who treats capital utilization as a synonym for shift-work. Interestingly enough, the other modern pioneer, Georgescu-Roegen (for example, 1972), stresses the choice of the daily duration of operations, acknowledges Marx's emphasis on the topic, but overlooks Marshall as well as Marris. Both view the choice of duration at the plant level, either directly or through the selection of a shift-work system, as a long-run or *ex ante* decision, that is, before the plant is built. Moreover, both assume the *ex post* elasticity of substitution to be zero, that is, within the day no variations in choice of technique are allowed once the factory is built. However, while Marris uses discrete techniques of production and discrete systems of utilization to describe the structure of the firm's optimization problem, Georgescu-Roegen uses a continuous production function and a

continuous index of the daily duration of operations; these differences of method do not generate substantial differences in results.

Both economists use their analyses to argue against anachronistic social legislation and draw implications from their work for an important contemporary economic problem, namely, the improvement of economic conditions in developing countries.

Before presenting the modern theory and its applications it is useful to note a few salient facts. Thanks to Foss's efforts (1981) there are reliable estimates of the average workweek of capital (plant hours) in US manufacturing for 1929 and 1976 – 67 and 82 hours, respectively. These estimates can be compared to an average workweek for labour of 50 hours in 1929 and 40 hours in 1976. Furthermore, Foss views the rise in capital's workweek between 1929 and 1976 as an underestimate of the increase in shift-work, because of the decrease in the number of days worked per week during this same period. The most thorough update of this data work is Beaulieu and Mattey (1998). It generates an average workweek of capital for manufacturing during the period 1974–92 of 97 hours per week. These 'facts' underlie interest in the topic and the frequent identification of capital utilization with shift-work.

Modern theory and applications

A number of contributions have incorporated the choice of duration into the neoclassical theory of the firm. This work is most concisely exposited using a model which relies on duality theory to generate the main results available in this literature (see Betancourt, 1986).

The firm's optimization problem is viewed as a two-stage procedure. In the first stage the decision-maker generates a cost function for each given level of duration; in the second stage the decision-maker selects from these cost functions that one which leads to least total cost. The end result in the two-input case is:

$$C^* = dC(w^*, r^*, x^*). \qquad (1)$$

For a given reference unit of duration, w^* represents the average wage rate, r^* the price of capital services, x^* the level of output, while d represents an index of duration of operations, C is a classical cost function, and C^* represents the total cost of operations at the optimal level of duration.

For example, if an eight-hour shift starting during normal hours is the reference unit of duration, as duration increases beyond this reference period: the average wage rate (w^*) increases because of shift differentials due to workers' preferences for normal hours or social legislation; and the price of capital services per eight-hour shift decreases, although there will be two opposite tendencies in this case. The daily price of a unit of capital increases due to the additional wear and tear created by the longer duration, but this price is now spread over a greater number of hours, and the price of capital services per eight-hour shift (r^*) decreases. Betancourt and Clague (1981, ch. 2, sect. 2) provide a detailed discussion of why the second effect predominates. Finally, as duration increases, the same daily output is spread over a greater number of hours, and the level of output per eight-hour shift (x^*) decreases.

The formulation in (1) yields the main insights about capital utilization or shift-work at the plant level offered by the early literature that followed Georgescu- Roegen and Marris. A brief listing of these results is as follows: (i) high shift differentials or overtime rates discourage capital utilization by increasing w^*; (ii) technologies with high degrees of returns to scale discourage utilization by raising the costs of operating at low levels of output (x^*); (iii) technologies with high degrees of capital intensity encourage capital utilization because the consequent fall in the relevant cost of capital (r^*) affects a higher percentage of costs; and (iv) technologies with abundant *ex ante* substitution possibilities encourage utilization because they lower the costs of taking advantage of the consequent fall in the cost of capital (r^*) through the building of a more capital intensive factory. These four factors are the main long-run determinants of optimal duration on the cost side.

In addition, two other characteristics of the utilization decision are worth stating. First, factories built to operate at high levels of utilization will be designed to use capital-intensive techniques. Second, how exogenous changes in input costs affect duration depends critically on the *ex ante* elasticity of substitution. For instance, if this elasticity is greater than unity, under constant returns to scale an exogenous fall in the price of capital lowers the costs of building the plant to operate longer hours.

One application of the model is as the theoretical basis for empirical studies of the choice of duration at the plant level. The model's implications were consistent with

several different bodies of plant level data (see Betancourt and Clague, 1981, chs 4–8) across non-continuous process industries. Recent work using more detailed plant level data for specific industries, for example automobiles, confirms the role of the number of shifts as a long-run margin of adjustment and it stresses the importance of changes in duration through overtime and daily closings as short-run margins of adjustment in the United States (Bresnahan and Ramey, 1994). Detailed studies of the auto industry for Europe and Japan (Anxo et al., 1995, chs 12 and 13, respectively) are also consistent with this long-run role for the number of shifts. Mayshar and Halevy (1997) develop a model that allows for *ex pos*t substitution possibilities as a short-run margin of adjustment. The above studies imply that there is a choice of duration, even in the short run, but in some industries continuous processes dominate and the choice is really to operate or not operate the process. A major extension of the model that captures this feature is provided by Das (1992), who develops and estimates a discrete dynamic programming model for the cement industry at the kiln level. In this context a plant is basically an additive collection of kilns and Das allows for three decisions, namely, operate, retire or keep idle a kiln in any plant.

Alternative approaches to the non-convexities that arise at the plant level have been developed by looking at the industry as the unit of analysis. Prucha and Nadiri (1996) provide an insightful and sophisticated example of this option applied to the US electrical machinery industry by making endogenous the capital utilization decision in the context of dynamic factor demand models. In a similar industry setting, Cardellichio (1990) uses the assumption of Leontief production functions at the mill level to analyse utilization for the lumber industry as a whole.

From a theoretical perspective an application of the model in (1) has been as the basis for the choice of duration in standard two-sector general equilibrium models. In the context of the international trade literature, Betancourt, Clague and Panagariya (1985), for example, use the specific-factors model with variable utilization to reconcile the dual scarcity explanation of Anglo-American trade in the 19th century with the empirical evidence on observed utilization levels. In the context of the public finance literature Coates (1991) generalizes the standard analysis of the incidence of the corporate profits tax by allowing for variable utilization. He concludes that overestimates of the burden of

the tax in the order of 10–60 per cent are most probable as a result of ignoring this long-run margin of adjustment in a general equilibrium context. A more abstract general equilibrium approach allowing for firm's decisions over duration and starting times as well as for worker's preferences over these work schedules has been developed recently by Garcia Sanchez and Vazquez Mendez (2005). Its main substantive result replicates one partial equilibrium result noted above, namely, that high capital intensity in the form of a high capital–labour ratio leads to an increase in utilization.

A short-run perspective has played an important role in dramatizing the policy implications of high levels of utilization for employment and output, since in this perspective a doubling of utilization implies a doubling of employment and output. Nevertheless a long-run perspective (see Betancourt and Clague, 1981, chs 9–11) provides a far less optimistic view about the likelihood of these outcomes. Ironically the evaluation of a shorter workweek for labour in Europe, which is analytically similar, has been carried out primarily from a short-run perspective (for example, Anxo et al, 1995, ch. 14). Garcia Sanchez and Vazquez Mendez (2005), however, suggest this topic as one for potential application of their long-run model.

Related issues: speed and capacity

The relations between duration, speed and capacity are difficult to analyse and provide an opportunity for confusion. To start, consider a dual representation of the cost function in (1). Namely,

$$x = dF(K,L) \qquad (2)$$

where x is the level of daily output, that is, $x = dx^{*} = dF$; F is a neoclassical production function defined over the reference period of duration; K represents both the level of the capital stock employed and the rate of capital services, which implies that the speed of operations (v) is constant and set at unity; and L represents labour services per reference period of duration. Alternatively, those who analyse variations in utilization through choice of speed represent the productive process as follows:

$$x = F(vK,L) \qquad (3)$$

where all variables have been previously defined. In (3) duration is set at unity.

Writers who employ (3) assume that the price of the capital stock is an increasing function of speed or utilization (for example, Smith, 1970). Since costs are defined as $C = r(v)K + wL$, where $r'(v) > 0$, the cost of a unit of capital services obtained by increasing speed is an increasing function of v. While in the duration model the price of the capital stock $r(d)$ is an increasing function of duration ($r'(d) > 0$), the cost of a unit of capital services obtained by increasing duration is a decreasing function of duration, that is, $r^* = r(d)/d$ and $r^{*'}(d) < 0$. This difference implies that models with one utilization variable to describe the productive process can generate nonsensical economic results if this variable is interpreted as representing either duration or speed, because the behaviour of costs can represent only one of the two interpretations. To illustrate, a recent body of literature relates capital utilization, economic growth and the speed of convergence (for example, Chatterjee, 2005), by assuming depreciation to increase with utilization at an increasing rate. This makes sense if one justifies increases in utilization as a result of increases in speed. Yet this literature justifies increases in utilization as a result of increases in duration through increases in the average workweek of capital.

Another interesting feature of the 'speed' model stems from the first-order conditions for cost minimization, which can be used to show that, if v, K and L are treated as choice variables, at the optimum, $r(v) = r'(v)v$. When duration and speed are endogenous this characteristic generalizes to $r(v, d) = r_v(v, d)\, v$ and optimal speed is determined by optimal duration (Madan, 1987). This is consistent with the finding by Bresnahan and Ramey (1994) for the auto industry that line speed and the number of shifts are long-run margins of adjustment.

Consider now the representation of the productive process underlying the typical definitions of capacity utilization. Namely,

$$x = F(K, L) \qquad (4)$$

where all variables are defined as before and speed and duration set at unity. Using (4), Panzar's (1976) definition of capacity becomes:

$$h(K) = \max_{L} F(K, L) \qquad (5)$$

where $h(K)$ is an increasing function of K. This definition leads to an output-based definition of short-run capacity utilization; that is:

$$CU = x/x\max \qquad (6)$$

where x max is given by (5).

When capital equipment is capacity-rated in terms of output units, as in electricity generation, one can measure directly the denominator of (6) and short-run capital and capacity utilization coincide (cf. Winston, 1982, ch. 5). In general, however, the denominator in (6) is not well defined. An alternative procedure is to define the denominator in (6) as the optimal level of output, x^0. For instance, in the literature on dynamic factor demand models x^0 is defined as the optimal level of output when the capital stock is endogenous (for example, Morrison, 1985; also see Prucha and Nadiri, 1996, for a generalization). Since 'optimal' output varies with the specification of the optimization problem, one can generate a variety of reasonable definitions of capacity utilization which measure different concepts. Not surprisingly, the corresponding empirical definitions fail to move together (de Leeuw, 1979) or with the average workweek of capital (Beaulieu and Mattey, 1998).

Implications

Perhaps the most important economic implication of the analysis of capital utilization above is for our understanding of technical change at the aggregate level. Ignoring increases in duration understates the contribution of capital services to output growth and, thus, overstates the estimates of technical change or the Solow residual in standard sources of growth analysis. Beaulieu and Mattey's estimate of the annual rate of growth in the average workweek of capital for manufacturing over the 1974–91 period is 0.17. They use employment per shift as weights, which are the appropriate ones, and find that only 25 per cent of the variation in growth can be accounted for by overtime.

Macroeconomists have pursued this issue but emphasized its business cycle implications. That is, when the Solow residual is adjusted for the workweek of capital it ceases to be pro-cyclical. For instance, Shapiro (1993) made this point in a widely cited paper. His results continued to hold in Beaulieu and Mattey's more recent data and they have given rise to a substantial literature that we will not explore here. One implication of this finding noted by Shapiro is that it casts doubts on alternative explanations of the

behaviour of the residual stressing market power when there are substantial costs to adjusting the workweek of capital, for example through the shift differential.

There is an early literature on the human costs of shift-work which may be captured through the shift differential. Betancourt and Clague (1981, ch. 12) conclude from their review of this literature that observed shift differentials of four to five per cent in the United States substantially underestimate the human costs of shift-work. This conclusion is consistent with estimates in an unpublished paper by Shapiro (1995) that the marginal shift premium is 25 per cent. A strand of literature in labour economics on compensating differentials has considered shift-work. Kostiuk (1990) obtains estimates of the shift differential of well above ten per cent in the unionized sector for both 1979 and 1985. He relies on Census of Population Survey data for his analysis.

An issue neglected in the recent literature is the role of obsolescence in capital utilization. Marris (1964) argued that an increase in the rate of obsolescence should strengthen the economic incentive for shift-work, since it ameliorated disincentive effects of wear and tear depreciation. In the last few decades we have observed systematic shifts from mechanical technologies to electronic technologies, which diminish wear and tear costs and increase the rate of obsolescence. This shift should, thus, have provided an incentive for increased capital utilization. Yet, to my knowledge, the economic literature has not addressed this issue explicitly.

Finally, an important reason for interest in capital utilization as an economic variable is the existence of transaction costs and market imperfections. These frictions make ownership of capital equipment and structures attractive relative to rentals for instantaneous capital services. Of course these rental markets do not exist in most cases. A substantial recent literature in industrial organization investigates the effect of transaction costs, including incompleteness of contracts and agency costs, on incentives and the evolution of institutions. With one exception, it has not addressed the impact of changes in transaction costs and market imperfections on capital utilization. The exception is the work of Hubbard (2003) on the trucking industry. He shows that improvements in monitoring technology in the form of on board computers increase capacity utilization, which in this industry coincides with short-run capital utilization just

as in the electricity generation industry. Issues of long-run capital utilization and relevance for other industries, however, remain unexplored in this context.

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See also **adjustment costs; fixed factors; labour market institutions**

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