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capital utilization. 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 current theorizing on this topic. Finally, the links to the issues of speed and capacity are set forth in detail.

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, e.g. 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 (1874) and maintained his interest in the topic throughout his career (e.g. see his work on Industry and Trade [1923, p. 650] and the *Principles* [1920, p. 578]).

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 (1969, 1970, 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 for the improvement of economic conditions in developing countries.

Before presenting the modern theory it is useful to note a few salient facts. Thanks to Foss's efforts (1981) there are reliable estimates of the average work-week of capital (plant hours) in US manufacturing for 1929 and 1976, 67 and 82 hours, respectively. These estimates can be compared to an average work-week for labour of 50 hours in 1929 and 40 hours in 1976. Furthermore, Foss views the rise in capital's work-week 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. These facts underlie recent interest in the topic and the frequent identification of capital utilization with shift-work.

CURRENT STATE OF THE THEORY: DURATION. A substantial number of recent contributions, based on the work of Marris and Georgescu-Roegen, have incorporated the choice of duration into the neoclassical theory of the firm. This work is most concisely explicated using a model which relies on duality theory to generate the main results available in this literature (cf. 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

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

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: a unit of capital increases due to the longer duration created by the longer duration of a greater number of hours, an eight-hour shift (r^*) decreases. ch. 2, sect. 2) provide a detailed effect predominates. Finally, daily output is spread over a level of output per eight-hour

The formulation in (1) yields about capital utilization or shift-work (Winston and McCoy (1974), Clague (1975)). A brief listing of high shift differentials or overutilization by increasing w^* , (i) of returns to scale discourage operating at low levels of output, high degrees of capital intensity because the consequent fall in output affects a higher percentage of abundant ex-ante substitution because they lower the cost of consequent fall in the cost of a more capital intensive factor.

These four factors are the optimal duration on the cost characteristics of the utilization. First, factories built to operate are designed to use capital-intensive exogenous changes in input critically on the ex-ante elasticity if this elasticity is greater than scale, an exogenous fall in the cost of building the plant to operate.

A logical extension of (1) all daily output under the assumption. While the main results discussed additional result is obtained: w depends on the level of output. U-shaped cost curve, the high utilization systems are the most

One application of the model empirical studies of the choice Clague, 1981, chs 4-8). It is implications emphasized about different bodies of data. Further provides a convenient point of that are directed at more farm production but make duration: has been to include choice equilibrium models of internal the specific-factors model with Clague and Panagariya (1985) nation of Anglo-American trade empirical evidence on observed general equilibrium models used in the public-finance literature to this field in the near future.

A short-run perspective has dramatizing the implications employment and output, since utilization implies a doubling a forceful and optimistic discourse outcome through policy manipulation for a less optimistic, long-run

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 all but one of the main insights about capital utilization or shift-work offered by, for example, Winston and McCoy (1974), Baily (1976) and Betancourt and Clague (1975). 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; (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.

A logical extension of (1) allows for an endogenous choice of daily output under the assumption of profit maximization. While the main results discussed earlier continue to hold, an additional result is obtained: when the degree of returns to scale depends on the level of output (x^*), as in the standard U-shaped cost curve, the higher the level of daily output, dx^* , permitted by demand conditions, the more likely that the high utilization systems are the most profitable.

One application of the model is as the theoretical basis for empirical studies of the choice of duration (cf. Betancourt and Clague, 1981, chs 4-8). It is worth noting that the model's implications emphasized above were not rejected by several different bodies of data. Furthermore, the duality formulation provides a convenient point of departure for empirical analyses that are directed at more familiar topics in the economics of production but make duration endogenous. Another application has been to include choice of duration in standard general equilibrium models of international trade. For example, using the specific-factors model with variable utilization, Betancourt, Clague and Panagariya (1985) reconcile the dual scarcity explanation of Anglo-American trade in the 19th century with the empirical evidence on observed utilization levels. Since the same general equilibrium models underlie the analysis of many topics in the public-finance literature, one would expect applications in this field in the near future.

A short-run perspective has played an important role in dramatizing the 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. For a forceful and optimistic discussion of the feasibility of this outcome through policy manipulation, see Schydlowky (1979); for a less optimistic, long-run appraisal, see Betancourt and

Clague (1981, chs 9-11). From a theoretical standpoint the heterogeneous capital-goods model of Solow, as developed in Mann (1984), provides the most drastic departure from the previous model. To analyse utilization at aggregate levels, Mann's model has a very attractive property: one can predict the effect on utilization of exogenous changes in the prices of capital and labour without knowing the elasticity of substitution. This same characteristic, however, limits its usefulness for understanding the duration decision at the plant or process level.

RELATED ISSUES: SPEED AND CAPACITY. The relations between duration, speed and capacity are difficult to analyse and are neglected in the literature. To start, consider a dual representation of the cost function in (1). Namely;

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

where x is the level of daily output, i.e. $x = dx^* = dF$; 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:

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

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 (e.g. 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, i.e. $r^* = r(d)/d$ 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 only represent one of the two interpretations.

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 (cf. Madan, 1985).

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

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

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

$$h(K) = \max_L F(K, L) \quad (5)$$

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

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

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 (e.g. Morrison, 1985) x^0 is defined as the optimal level of output when the capital stock is endogenous. Since this literature implicitly assumes constant duration in both the short-run and the long-run, there is no relation between this measure of capacity utilization and capital utilization. Moreover, 'optimal' output varies with the specification of the optimization problem, and 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). To conclude, many theoretically plausible alternatives for integrating capital and capacity utilization exist.

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See also FIXED FACTORS; HOURS OF WORK.

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Carey, Henry Charles (1793-1879). American social scientist. Born in Philadelphia, the son of Mathew Carey, he was a prolific author, and his influence, though shortlived, spread from Pennsylvania throughout the nation and to Europe.

Carey's economic views were sharply at variance with those of Ricardo and Malthus, and reflect the optimism characteristic of American conditions favourable to economic expansion, conditions from which Carey himself benefited as a successful entrepreneur and promoter. The two leading themes of his writings were protectionism and harmony of interests. In his first book, *Essay on the Rate of Wages* (1835), he opposed trade restrictions as running counter to the providential order. But in *The Past, the Present and the Future* (1848) and in later writings, he vigorously appealed for tariff protection as fulfilling his law of association, a law that called for diversified and balanced regional development. Narrow specialization and foreign trade would violate this law. In *The Slave Trade* (1853) Carey suggested protectionism for the South, where it would foster industrial development.

The scope of Carey's optimistic belief in a harmonious order gradually widened. In his first book he postulated harmony between capitalists and workers, the former benefiting from rising profits and the latter from wages that rose as a result of the accumulation of capital. In his *Principles of Political Economy* (1837-40) the landowner becomes part of the harmonious order, with his earnings depicted as a return on his capital rather than a gift of nature. Population growth does not disturb the harmony as it is restrained by social conditioning. There are further attacks against the Ricardian rent theory in *The Past, the Present and the Future*, where cultivation is said to move from inferior to superior land, not vice versa as Ricardo had taught, and with returns increasing rather than decreasing. In the *Principles of Social Science* (1858-9) Carey expands his vision of a harmonious order to apply to the universe, and in *The Unity of Law* (1872) he maintains that cosmic and social laws are identical. Carey has been characterized as 'easily the most perverse and the most original American political economist before Veblen' (Conkin, 1980, p. 261).

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SELECTED WORKS

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