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CAPACITY, CAPACITY UTILIZATION, AND THE ACCELERATION PRINCIPLE

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This paper presents empirical findings about the cyclical behavior of capacity and capacity utilization together with some observations about the causes and implications of that behavior. The assumptions and predictions of the acceleration principle receive particular attention. Some historical observations on capacity growth and utilization in peacetime and wartime are also offered. Finally it is hoped that the paper will acquaint the reader with the available data and the conceptual problems involved in their use. The data employed are annual estimates of capacity and production for a group of thirteen industries.

The Concept of Capacity and the Published Estimates

Statistical measures of capacity of the type used here have three basic characteristics. They assume (for each firm) given plant facilities, an uninterrupted flow of variable inputs such as labor and materials, and a "normal" organization of production. In addition they may or may not include an allowance for seasonal fluctuations in output or for unavoidable shut-downs. Usually these latter factors are accounted for by a distinction between "theoretical" or "rated" capacity and "practical" capacity, where the former is based on the first three assumptions listed above. A list of the series used is presented in Appendix A along with the principal characteristics of each.

Although the following discussion is couched in terms of the individual firm, the estimates are generally available only as industry aggregates. From the viewpoint of economic analysis, the primary attribute of the data is that they employ an engineering

Note: This paper is an expanded version of a report on research in progress that was delivered at a round table discussion at the Conference. The author is particularly indebted to Franco Modigliani for his criticisms of the original report and his valuable suggestions concerning the revision. He is also indebted to Rudolph Blitz, Robert Eisner, and Robert H. Strotz for comments on various portions of the paper and to David Sher for research assistance.

rather than a cost concept of capacity. The question posed is this: How much physical output can be produced with a given plant under a normal organization of production and with an uninterrupted and unlimited flow of variable inputs? Even this question cannot be answered unambiguously in all circumstances. For example the capacity figures for cotton-spinning, petroleum-refining, and paper-making can vary as the specifications of the product produced vary. Also, what is a "normal organization of production"? Thus cotton mills can be operated for one, two, or three shifts, as the circumstances warrant. Fortunately this multiple-shift problem is eliminated in most of the series used since the majority of the products are produced under conditions of continuous twenty-four-hour operation.

What restrictions does the noncost character of the data place on their usefulness to the analyst? As is usually the case, the answer depends in considerable part on the purpose of the analyst. If he is interested in quantitative analysis of the efficiency of allocation of resources, his concern is precisely with the cost concept of capacity, and engineering data are practically useless—unless a precise relationship between the engineering and cost estimates can be established. Nevertheless there are certain definite and important parallels between the cost and engineering concepts. As a matter of fact the subsequent discussion will show that there is no essential dichotomy between the two concepts *in qualitative terms*.

In discussions of resource allocation, the usual practice is to define capacity as that output which may be produced at minimum average total cost, when the prices of resources and the production function of the firm are given. As long as the cost function is fixed, the capacity of the firm is fixed. The actual output of the firm may exceed or fall short of the capacity output—that is, capacity utilization may be greater or less than 100 per cent—but with free entry and exit in a competitive industry overutilization and underutilization would tend to be eliminated in the long run. Since primary interest is in long-run phenomena, abstraction is usually made from seasonal and cyclical fluctuations in defining the cost function. In fact only two types of change in the cost function (and hence in capacity) are admitted to the analysis: structural changes in factor prices which reflect changes in the relative valuations of resources in alternative employments, and changes in the production function. The first type of change has no analog in the engineering concept of capacity (except insofar as the engineering capacity is altered by changes in the organization of production induced by price changes) but the latter type does since changes in plant and equipment, the normal work week, the normal number of shifts, etc. influence rated capacity.

It is apparent that the investigator who wished to quantify the rigorous cost concept would face a difficult task. He would have to use some "normal cost" concept which abstracted from seasonal and cyclical changes in factor prices, yet which admitted structural price changes (if he were interested in changes in capacity). He would also have to distinguish private and social costs if he were interested in the efficiency of allocation of resources.

Changes in efficiency—in cost per unit of output—as output is varied along a *given* cost function do not affect capacity. For example changes in average cost due to the operation of the law of variable proportions are already defined in the cost function, and the minimum point on the cost function fixes the capacity output. High or low rates of utilization may involve increased costs per unit of output, but this is precisely because capacity does not change. Again, differences in the quality of individual units of inputs do not affect capacity either because homogeneous units are assumed, or because some sort of efficiency unit is defined, or because the cost function is defined to allow for variations in the quality of inputs. All such influences will also be reflected in utilization ratios based on the engineering data. Even if engineering capacity is defined independently of cost, the rate of utilization is not independent of price-cost relationships.

Changes in efficiency which involve shifts of the cost function may change capacity. At constant factor prices, such shifts will result from the introduction of new machinery, new processes, reorganizations of production, etc. Since capacity has changed, the behavior of the utilization ratio depends on the shapes and positions of the cost and revenue functions before and after the innovation. As has already been pointed out, influences of this type will alter the figures on engineering capacity, which will also reflect such changes in the organization of production as are induced by changes in relative factor prices.

Another class of problem is that of estimating peak production potentials. There are really two questions involved here: Can peak capacity be estimated, and can full utilization of peak capacity be attained? Neither of these questions can be answered by the published data alone since there will be different answers for different economic conditions.

Conceptually peak capacity would be that output at which the average total cost function became vertical. Whether such a limit really exists, or whether it is always possible to get a little more output by the expenditure of a sufficiently lavish amount of resources, are not questions to be considered here. However, raising the problem suggests several questions that should be addressed to the published data. For example is capacity defined for a maximum work week or can it be increased by longer hours or by multiple-shift operations? In cotton-spinning, the number of spindles in place declined from 36.7 million in 1927 to 23.0 million in 1950, but the number of spindle-hours run increased from 102.6 billion in 1927 to 116.1 billion in 1950. The increase in hours run per spindle was primarily the result of the increased use of multiple shifts. Again, the data for some industries exclude the capacities of long-idle plants which can and will be reactivated if demand warrants it.

The question of the attainable rate of utilization again leads into price considerations. Many of the industries in our collection reached higher rates of utilization during World War II than in peacetime.[1] It is entirely possible that these wartime rates of utilization were simply not attainable under peacetime conditions. The published data reveal nothing about the age distribution and general efficiency of the production units included in the capacity totals. A considerable fraction of the rated capacity in a particular industry may be so marginal that it can be profitably employed only under wartime or other abnormal conditions of demand.

Seasonal fluctuations in production also have an important bearing on the attainable annual rate of utilization. War conditions may have virtually eliminated seasonal fluctuations in production stemming from the demand side. This factor could go a long way toward explaining the high annual rates of utilization of the war years. The problem of seasonal fluctuation appears in extreme form in the electric power industry. The utilization ratio on an annual basis never rose above 39 per cent in the 1920's or 1930's, and the maximum ratio attained in the 1940's was 59 per cent (1948). One of the principal reasons for these low ratios is that power companies must be prepared to meet peak loads on demand, and there is extremely wide intra-annual variation in the demand for electric power.

These comments serve to emphasize the caution with which inferences should be drawn from utilization ratios based on the engi-

[1]See Table 10.

neering data. In particular, statements that peak rates of utilization are low and that excess capacity exists should be made with care.

One final point: if an attempt were made to estimate the peak production potential for a substantial segment of the economy from capacity data for individual industries, it would be necessary to take into account the relations among the various industries and the general availability of resources since the capacity estimates for each industry assume the ready availability of all resources other than productive facilities.

Secular and Cyclical Variations in Capacity

When the capacity series are plotted, capacity appears to increase almost continuously in growing industries and to decrease almost continuously in declining industries—the direction of capacity change seems to be largely independent of cyclical fluctuations in output. This visual impression is confirmed when the data are studied in more systematic fashion.

The number of years during which capacity changed in the same or opposite direction as production, during expansions and contractions of production, is shown in Table 1, with the industries grouped by type of secular change. Capacity decreased infrequently during expansions of production and increased frequently during contractions of production in industries experiencing secular growth of capacity. The opposite was the case in industries experiencing secular decline.[3] The same generalizations hold when comparisons are made with a one-year lag of capacity change behind production change.

At first sight, capacity in the remaining industries appeared to display somewhat greater cyclical sensitivity. However, inspection of the plotted data disclosed that these industries had experienced mixed secular change. When periods of growth and decline were marked off by visual inspection and separate comparisons made for the subperiods, it was found that changes in capacity in these industries were also influenced by secular growth or decline.

At first thought these results are somewhat surprising to anyone accustomed to thinking of capital formation as the major cause of capacity change and as displaying wide cyclical variation. However, reflection indicates that the findings are not really startling. First it is also usual to think of capital formation in individual in-

[3]Incidentally, about one-half of the cases of capacity growth during expansions in the beehive-coke and wheat-flour industries occurred during World War II.

TABLE 1

Years in Which Capacity Changed in Same (+) or Opposite (−) Direction as Production: Total, and During Expansions and Contractions of Production, 1908–1951.

Industry	Period Covered	Growth Characterization	Simultaneous Changes of Capacity and Production						One-Year Lag of Capacity Change behind Production Change					
			Total		Expansions		Contractions		Total		Expansions		Contractions	
			+	−	+	−	+	−	+	−	+	−	+	−
A. Industries Experiencing Secular Growth of Capacity														
By-product coke	1910–1949	Growth	24	13	22	4	2	9	24	12	22	3	2	9
Steel ingots	1914–1951	Growth	22	15	20	5	2	10	23	13	20	4	3	9
Petroleum refining	1917–1949	Growth	28	4	25	1	3	3	27	4	25	1	2	3
Electric power	1921–1951	Growth	23	7	23	2	0	5	22	7	22	2	0	5
Paper	1917–1950	Growth	25	7	23	1	2	6	23	8	22	2	1	6
High explosives	1922–1951	Growth	17	12	15	5	2	7	15	13	14	5	1	8
B. Industries Experiencing Secular Decline of Capacity														
Beehive coke	1908–1949	Decline	23	16	6	14	17	2	21	17	5	15	16	2
Wheat flour	1923–1951	Decline	16	12	7	10	9	2	18	9	8	8	10	1
Cotton spinning	1922–1950	Decline	13	15	3	12	10	3	12	15	2	12	10	3
Black blasting powder	1922–1951	Decline	21	8	7	6	14	2	16	12	4	7	12	5
C. Industries Experiencing Mixed Secular Change of Capacity														
Portland cement	1909–1949	Mixed	24	16	19	8	5	8	25	14	19	7	6	7
	1909–1932	Growth	15	8	14	1	1	7	16	7	14	1	2	6
	1933–1949	Decline	9	8	5	7	4	1	9	7	5	6	4	1
Electrolytic copper	1906–1949	Mixed	22	17	17	7	5	10	25	13	19	5	6	8
	1906–1918	Rapid gr.	9	3	9	0	0	3	10	2	9	0	1	2
	1919–1934	Slow gr.	11	4	7	1	4	3	10	5	7	2	3	3
	1935–1949	Decline	2	10	1	6	1	4	6	5	3	3	3	2

(continued on next page)

TABLE 1 (continued)

Industry	*Period Covered*	*Growth Characterization*	*Simultaneous Changes of Capacity and Production*						*One-Year Lag of Capacity Change behind Production Change*					
			Total		*Expansions*		*Contractions*		*Total*		*Expansions*		*Contractions*	
			+	–	+	–	+	–	+	–	+	–	+	–
C. Industries Experiencing Mixed Secular Change of Capacity (continued)														
Pig iron	1913–1951	Mixed	22	16	18	7	4	9	25	12	19	5	6	7
	1913–1924	Growth	6	5	6	0	0	5	7	4	6	0	1	4
	1925–1939	Decline	5	10	3	7	2	3	10	5	6	4	4	1
	1940–1951	Growth	11	1	9	0	2	1	8	3	7	1	1	2

Note: The dates of the peaks and troughs are those of the individual cycles in each production series. Every reversal of production was treated as initiating a cyclical phase. In some industries there were years in which no change of capacity occurred and consequently in which the number of observations is less than the number of years covered. Also, one observation is lost when the lag of capacity change behind output change is introduced.

dustries as dominated by secular growth, as in the application of the acceleration principle to the long-run growth of an industry. Wide fluctuations in aggregate capital formation over the business cycle are not at all inconsistent with investment in some industries and disinvestment in others. Secondly it may take considerable time to put new facilities into place, and it is reasonable to expect that projects initiated during upswings will often carry over for a year or two into contractions. Even if growing industries initiated no new expansion programs during cyclical contractions of output, a net increase in capacity could occur because of this lag. On the other hand, capacity growth is also common during the initial years of upswings because some new projects are initiated during the preceding contractions. Finally disinvestment of physical capacity is a time-consuming process. If cyclical declines in demand lead some firms to failure, that in itself takes time; even then the facilities may pass into the hands of new owners, particularly if the contraction proves to be brief. Disinvestment which results from the failure of continuing firms to replace deteriorated facilities is also likely to be drawn out. It is probable that unless contractions are prolonged and severe, neither the time nor the desire to disinvest will be present in growing industries.

It is interesting that in a majority of the growing industries capacity decreased more often during years of expansion than during years of contraction. However, most of these cases occurred during the long and feeble expansion of 1933–1937, which followed three years of sharp contraction (Table 2). Generally low rates of capacity utilization prevailed throughout this eight-year period. It is apparent that the burden of excess capacity during a major depression inhibits capacity growth even in industries undergoing secular expansion.

To sum up: capacity change, and by inference fixed investment, in particular industries is dominated by secular growth. In the case of growing industries, the secular expansion of output makes for relative immunity to cyclical contractions—note the small number of years of contraction experienced by growing industries (Table 1). Furthermore in growing industries contractions of production do not usually prevent the expansion of capacity because projects initiated during upswings carry over a year or two into contractions, and because favorable longrun expectations encourage investment even during periods of depressed demand. In the absence of long periods of cyclically depressed demand, capacity expansion may be expected to be virtually continuous in such industries. On the other

TABLE 2

Capacity Increase (+) or Decrease (–) in Industries Experiencing Secular Growth, and Capacity Utilization Ratios, 1930–1939

(per cent)

Industry	Extreme Rate of Utilization,[a] 1919–1929 High	Low	1930 Capacity Change	1930 Utilization	1931 Capacity Change	1931 Utilization	1932 Capacity Change	1932 Utilization	1933 Capacity Change	1933 Utilization	1934 Capacity Change	1934 Utilization
By-product coke	89.2	45.5	+	74.1	+	51.8	+	33.4	–	42.4	0	48.9
Steel ingots	87.5	34.2	+	60.7	+	37.2	+	19.5	–	33.2	–	37.3
Petroleum refining	80.2	66.6	+	69.2	–	66.9	–	63.6	–	67.4	+	68.5
Electric power	39.2	32.4	+	33.4	+	30.2	+	26.6	+	27.1	–	29.0
Paper	84.1	61.9	–	74.5	+	67.1	–	58.3	0	66.9	+	66.1
High explosives	68.0	51.5	–	57.9	+	42.9	+	28.6	–	34.8	+	44.6

Industry	1935 Capacity Change	1935 Utilization	1936 Capacity Change	1936 Utilization	1937 Capacity Change	1937 Utilization	1938 Capacity Change	1938 Utilization	1939 Capacity Change	1939 Utilization
By-product coke	–	54.6	–	71.6	+	78.8	–	51.1	+	69.0
Steel ingots	+	48.8	–	68.5	+	71.5	+	39.2	+	64.6
Petroleum refining	+	71.9	+	75.9	+	81.7	–	80.8	+	83.4
Electric power	–	31.7	+	35.8	+	38.4	+	35.5	+	38.2
Paper	+	74.9	+	82.8	+	82.4	+	70.3	+	81.6
High explosives	+	43.9	+	55.7	+	58.9	+	49.6	+	59.5

[a]The utilization ratio is the ratio of production to capacity.

TABLE 3

Average Amplitudes of Production and Capacity during Cyclical Expansions and Contractions, 1907–1950
(units of each series [a])

Industry	*Period Covered*	*Growth Characterization*	*Expansions*		*Contractions*	
			Production	*Capacity*	*Production*	*Capacity*
A. Industries Experiencing Secular Growth of Capacity						
By-product coke	1913–1948	Growth	170	54	−100	18
Steel ingots	1917–1949	Growth	260	42	−193	15
Petroleum refining	1917–1948	Growth	135	111	−24	12
Electric power	1921–1945	Growth	696	954	−79	109
Paper	1920–1949	Growth	547	346	−175	32
High explosives	1926–1949	Growth	133	55	−59	12
B. Industries Experiencing Secular Decline of Capacity						
Beehive coke	1910–1948	Decline	497	−199	−777	−308
Wheat flour	1924–1950	Decline	146	−2	−110	−24[b]
Cotton spinning	1923–1949	Decline	231	−35	−195	−25
Black blasting powder	1923–1949	Decline	57	−143	−242	−260
C. Industries Experiencing Mixed Secular Change of Capacity						
Portland cement	1913–1944	Mixed	407	140	−351	31
	1913–1932	Growth	378	335	−355	64
	1933–1944	Decline	437	−56	−346	−13
Electrolytic copper	1907–1947	Mixed	498	140	−434	4
	1907–1932	Growth	412	255	−427	9
	1937–1947	Decline	515	−22	−449	−6
Pig iron	1914–1949	Mixed	172	24	−140	0
	1914–1924	Growth	128	14	−105	7
	1925–1938	Decline	157	1	−203	−9
	1939–1949	Growth	282	79	−116	1

[a] The units for each industry are as follows:

By-product coke	00,000 tons	Wheat flour	00,000 barrels
Steel ingots	00,000 tons	Cotton spinning	00,000,000 spindle-hours
Petroleum refining	0,000 barrels		
Electric power	00,000,000 kilowatt-hours	Black blasting powder	00,000 pounds
		Portland cement	00,000 barrels
Paper	0,000 tons	Electrolytic copper	000 tons
High explosives	000,000 pounds	Pig iron	00,000 tons
Beehive coke	0,000 tons		

[b] Excluding an extreme value associated with a change in the length of the working week after 1948 (see Appendix A). The average including the extreme value is −87.

Note: The amplitudes of the various industries are not comparable, but the amplitudes of production and capacity in the same industry are. The amplitude of each expansion is the algebraic change from the trough to the peak year; the amplitude of each contraction is the algebraic change from peak to trough. The average amplitudes are arithmetic means of the individual amplitudes. The dates of the peaks and troughs of production are those of the individual cycles in each series. Every reversal of production was treated as initiating a cyclical phase. The amplitudes of the corresponding phases in capacity are based on peaks and troughs which lag those in production. A lag of one year was used for most industries, but a two-year lag was employed for petroleum refining, electric power, and portland cement, and no lag was used for paper and black blasting powder.

Notes continued on next page

Notes to Table 3 (continued)

Only complete expansions and contractions are included; hence the periods covered are shorter than in Table 1. One expansion has been omitted in the subperiod averages for electrolytic copper since it overlapped the division between periods of growth and decline. The expansion in pig iron which began in 1939 has been included in the subperiod average for the growth period 1940–1951.

hand, disinvestment will be relatively continuous in industries experiencing secular decline—cyclical expansions of production will often fail to press heavily on available capacity or engender optimistic long-run expectations.

Cyclical Amplitudes of Capacity and Production

The average amplitudes of production and capacity during cyclical expansions and contractions are presented in Table 3. Where appropriate, the cycles are lagged behind those in production, as explained in note a of the table. Secular change again dominates the results. For example the average amplitudes of capacity are positive during contractions in industries experiencing secular growth and negative during expansions in the declining industries. Again, the cyclical amplitudes of capacity are smaller than those of production in all but two of the industries—a not unexpected result given the facts that capacity is relatively insensitive to cyclical changes in production and that production is increased or decreased by varying the rate of utilization as well as capacity.[3]

Would not the *rate* of change of capacity be modified by cyclical changes in production even if the direction of change were not? Granted that the investment horizon in a growing industry is relatively long, one would still expect that cyclical contractions of demand and production would slow the growth of capacity. Similarly it seems plausible that, in declining industries, the rate of disinvestment would tend to decrease during cyclical expansions of demand and production. The measures in Table 4 confirm these hypotheses. The average annual rates of increase of capacity were larger during expansions than contractions in the six growing industries and the average annual rates of decrease of capacity were larger during contractions than expansions in three of the four declining industries.[4] When the fact that the rate of increase of capacity in the growing industries tended to be greater during ex-

[3]The two exceptions—electric power and black blasting powder—respectively were experiencing such high rates of growth and decline (Table 9) that the secular changes in capacity were greater than the cyclical changes in output.

[4]The same tendencies hold for the periods of growth and decline in two of the three cases of mixed secular change.

TABLE 4

Average Annual Rates of Change of Production and Capacity during Cyclical Expansions and Contractions, 1907–1950

(*units of each series*[a])

Industry	*Period Covered*	*Growth Characterization*	*Expansions: Production*	*Expansions: Capacity*	*Contractions: Production*	*Contractions: Capacity*
		A. Industries Experiencing Secular Growth of Capacity				
By-product coke	1913–1948	Growth	59	19	−66	16
Steel ingots	1917–1949	Growth	91	15	−132	11
Petroleum refining	1917–1948	Growth	22	17	−14	14
Electric power	1921–1945	Growth	113	141	−50	84
Paper	1920–1949	Growth	120	67	−126	28
High explosives	1926–1949	Growth	47	14	−36	11
		B. Industries Experiencing Secular Decline of Capacity				
Beehive coke	1910–1948	Decline	249	−159	−561	−169
Wheat flour	1924–1950	Decline	41	−10	−43	−12[b]
Cotton spinning	1923–1949	Decline	103	−16	−134	−15
Black blasting powder	1923–1949	Decline	36	−74	−98	−151
		C. Industries Experiencing Mixed Secular Change of Capacity				
Portland cement	1913–1944	Mixed	137	13	−152	22
	1913–1932	Growth	97	49	−122	49
	1933–1944	Decline	178	−22	−193	−14
Electrolytic copper	1907–1947	Mixed	179	38	−164	3
	1907–1932	Growth	114	70	−137	12
	1937–1947	Decline	316	−7	−220	−15
Pig iron	1914–1949	Mixed	64	9	−103	2
	1914–1924	Growth	72	10	−105	7
	1925–1938	Decline	47	1	−119	−6
	1939–1949	Growth	73	21	−75	3

[a]See note a of Table 3 for units for each industry.

[b]Excluding an extreme value associated with a change in the length of the working week after 1948 (see Appendix A). The average including the extreme value is −33.

Note: The measures for different industries are not comparable, but the measures for production and capacity in each industry are. The total amplitudes of the individual expansions and contractions in production and capacity are calculated for each series as explained in the Note to Table 3. The total amplitudes were then divided by the number of years in each expansion or contraction. The resulting average annual rates of change were then averaged for all expansions and contractions in each series. Only complete expansions and contractions are included; hence the periods covered are generally shorter than in Table 1. One expansion has been omitted in the subperiod averages for electrolytic copper since it overlapped the division between periods of growth and decline. The expansion in pig iron which began in 1939 has been included in the subperiod average for the growth period 1940–1951.

pansions is coupled with the fact that those industries experienced many more years of expansion than contraction, it is easy to understand why the *total* amplitudes were so much larger during expansions than contractions (Table 3).

Cyclical Variations in Capacity Utilization

If capacity remained constant, the rate of utilization would vary directly with output. When both capacity and output change, the change in utilization depends on the relative changes in capacity and output. Since the cyclical amplitudes of capacity are typically smaller than those of production, and since capacity tends to move

TABLE 5

Number of Years in Which Production and Capacity Changed in the Same (+) or Opposite (–) Direction as the Rate of Utilization of Capacity during Expansions and Contractions of Production, 1906–1951

			Expansions				*Contractions*			
		Growth Characterization	*Production*		*Capacity*		*Production*		*Capacity*	
Industry	*Period Covered*		+	–	+	–	+	–	+	–
A. Industries Experiencing Secular Growth of Capacity										
By-product coke	1910–1949	Growth	21	6	16	10	12	0	2	9
Steel ingots	1914–1951	Growth	23	2	18	7	12	0	2	10
Petroleum refining	1917–1949	Growth	17	9	16	10	6	0	3	3
Electric power	1921–1951	Growth	19	5	17	7	5	0	0	5
Paper	1917–1950	Growth	16	9	15	9	8	0	2	6
High explosives	1922–1951	Growth	16	4	11	9	9	0	2	7
B. Industries Experiencing Secular Decline of Capacity										
Beehive coke	1908–1949	Decline	21	0	6	14	18	2	15	4
Wheat flour	1923–1951	Decline	16	0	6	10	8	3	6	5
Cotton spinning	1922–1950	Decline	15	0	3	12	12	1	9	4
Black blasting powder	1922–1951	Decline	10	3	4	9	12	4	10	6
C. Industries Experiencing Mixed Secular Change of Capacity										
Portland cement	1909–1949	Mixed	20	7	13	14	10	3	3	10
	1909–1932	Growth	8	7	8	7	7	1	0	8
	1933–1949	Decline	12	0	5	7	3	2	3	2
Electrolytic copper	1906–1949	Mixed	19	6	11	13	18	0	5	10
	1906–1934	Growth	12	6	10	7	10	0	4	6
	1935–1949	Decline	7	0	1	6	8	0	1	4
Pig iron	1913–1951	Mixed	21	4	14	11	13	0	4	9
	1913–1924	Growth	5	1	5	1	5	0	0	5
	1925–1939	Decline	10	0	3	7	5	0	2	3
	1940–1951	Growth	6	3	6	3	3	0	2	1

Note: In some industries there were years in which no change of capacity or utilization occurred and consequently in which the number of observations is less than the number of years covered. Capacity utilization is measured by the ratio of production to capacity.

inversely to output during contractions in growing industries and during expansions in declining industries, utilization tends to vary directly with output (Table 5). The number of opposing movements of production and utilization is a small minority in every industry. Almost universally the opposing movements occur on the upswings in growing industries and on the downswings in declining industries. Thus when utilization moves in opposition to production in a growing industry, it is because capacity has increased more rapidly than production during a year of expansion.

The opposing movements of capacity and utilization are more numerous. Consider the growing industries. In addition to those years when capacity increased more than production during upswings, causing utilization to fall, there are the years in which capacity decreased as production, and therefore utilization, decreased. Again, on numerous occasions capacity continued to grow as output and utilization declined during downswings. Similar remarks apply in the case of the declining industries. Considerably more often than not, capacity decreased as utilization rose along with production during upswings. Occasionally capacity and utilization moved inversely during downswings either because capacity fell more than output or because it increased.

Thus although utilization generally rises and falls in conformity with cycles in production, the same is not true of capacity. Since capacity tends to increase continuously in growing industries and to decrease continuously in declining industries, the direction of capacity change is largely independent of the direction of change in utilization.

Capacity Utilization and the Acceleration Principle

We may distinguish two versions of the acceleration principle as applied to cyclical fluctuations in production. In the strong version a fixed ratio of capital stock to output is assumed to hold continuously and net investment varies directly and proportionally with the rate of change of output. The existence of excess capacity is denied by assumption, and investment and disinvestment are treated symmetrically. This version of the acceleration hypothesis is clearly contradicted by our previous findings. Disinvestment rarely occurs during contractions in growing industries—the accelerator does not operate in the downward direction. On the other hand disinvestment occurs as often or more often than investment during expansions in declining industries—cyclical increases in production do not press heavily on capacity or create optimistic long-run expectations, and the accelerator does not operate in the upward direction.

In the modified version of the acceleration principle the assumption that a fixed ratio of capital stock to output holds at all times is relaxed. Thus the possibility of excess capacity is admitted to the analysis. For example the operation of the accelerator is suspended during the early portion of the upswing until unutilized capacity has been brought into operation. Furthermore since excess capacity is assumed in an initial stage of the upswing, it must have been present during the preceding contraction. Therefore any decline in capacity which takes place during the downswing cannot be proportional to the decline in output. Disinvestment can occur only through a failure to replace deteriorated facilities. The rate of replacement can drop to zero but no lower. Once this stage has been reached, disinvestment is a function of the rate of depreciation of the capital stock rather than of the current rate of change of production, and therefore excess capacity can develop during the downswing.[5] Thus in the modified version, the operation of the accelerator is largely confined to the latter portion of the upswing, although disinvestment may be proportional to the rate of decline in output during the initial stages of contraction while replacement is less than depreciation but still positive. However, the finding that investment is ordinarily positive during contractions in growing industries contradicts this part of the hypothesis, at least as applied to brief contractions. It is also apparent that the modified principle is not applicable to declining industries since surplus capacity is ubiquitous there.

The utilization ratios of the various industries at the peaks and troughs of *business cycles* are listed in Table 6. The average level[6] of the utilization ratios is of no importance in the present context—what *is* relevant is the spread between utilization ratios at peaks and troughs and the range of the utilization ratios attained at the various peaks.

The utilization ratios at the troughs are usually considerably lower than those at the peaks—a fact which stands out most clearly when adjacent peaks and troughs are compared. This fact is recognized in the modified version of the acceleration principle by sus-

[5]For a discussion of this point and of the modified acceleration principle in general, see J. R. Hicks, *A Contribution to the Theory of the Trade Cycle*, London, Oxford University Press, 1950.

[6]The average level depends primarily on the particular characteristics of each industry that govern the spread between rated capacity, which was used in computing the ratios, and practically attainable capacity.

TABLE 6

Utilization of Capacity at Business Cycle Peaks and Troughs, 1908–1949

(per cent)

	Business Cycle Peaks									
Industry	*1910*	*1913*	*1918*	*1920*	*1923*	*1926*	*1929*	*1937*	*1944*	*1948*
					A. Industries Experiencing Secular Growth of Capacity					
By-product coke	83.0	84.8	86.9	74.8	84.5	87.9	89.2	78.8	93.2	92.9
Steel ingots			83.1	74.6	76.1	82.0	87.5	71.5	94.8	93.1
Petroleum refining			72.0	71.5	68.5	79.1	77.8	81.7	93.3	92.3
Electric power					39.2	35.3	36.5	38.4	53.5	59.1
Paper			79.2	84.1	80.9	81.6	81.3	82.4	89.2	93.6
High explosives					63.0	68.0	65.1	58.9	77.3	85.7
					B. Industries Experiencing Secular Decline of Capacity					
Beehive coke	58.5	58.7	59.8	44.1	52.0	38.4	30.7	43.2	70.0	81.5
Wheat flour					52.2	54.2	57.2	53.0	67.5	76.7
Cotton spinning[a]					101.8	92.2	103.6	133.3	183.1	193.0
Black blasting powder					50.6	40.5	39.2	39.4	42.4	44.8
					C. Industries Experiencing Mixed Secular Change of Capacity					
Portland cement	66.5	70.2	49.1	68.3	86.5	77.0	67.6	45.5	37.6	81.6
Electrolytic copper	85.8	85.0	74.1	52.1	72.0	80.5	94.4	71.5	72.9	76.6
Pig iron		70.1	79.2	71.4	76.0	75.5	82.2	73.0	92.0	88.2

(continued on next page)

TABLE 6 (continued)

(per cent)

Industry	*1908*	*1911*	*1914*	*1919*	*1921*	*1924*	*1927*	*1932*	*1938*	*1946*	*1949*
	Business Cycle Troughs										
A. Industries Experiencing Secular Growth of Capacity											
By-product coke		76.9	67.6	69.4	45.5	73.9	79.4	33.4	51.1	75.7	81.2
Steel ingots			58.1	63.0	34.2	62.9	74.0	19.5	39.2	72.7	79.8
Petroleum refining				70.1	66.6	71.0	77.4	63.6	80.8	91.0	85.6
Electric power					32.4	37.3	35.5	26.6	35.2	50.7	55.5
Paper			80.0	77.8	61.9	75.5	79.8	58.3	70.3	94.4	84.8
High explosives						62.2	63.5	28.6	49.6	67.4	77.4
B. Industries Experiencing Secular Decline of Capacity											
Beehive coke	38.2	47.0	41.4	38.6	13.3	28.3	23.9	5.8	11.8	62.2	41.5
Wheat flour						53.5	54.2	52.2	54.6	76.7	78.0
Cotton spinning[a]						83.0	102.3	77.5	102.0	168.6	158.7
Black blasting powder						40.9	43.3	24.3	28.2	42.3	31.2
C. Industries Experiencing Mixed Secular Change of Capacity											
Portland cement		63.6	65.9	56.3	68.9	86.4	77.1	28.3	41.2	67.9	81.7
Electrolytic copper	75.2	82.7	77.8	58.7	35.3	82.1	76.2	22.3	51.7	54.9	65.3
Pig iron			51.9	61.5	31.7	58.6	70.4	17.0	37.2	68.2	76.3

[a]Measured on single-shift basis. See Appendix A.

Note: The dates of the peaks and troughs of business cycles are those of the National Bureau of Economic Research. The utilization ratio is the ratio of production to capacity.

pending the operation of the accelerator in the early portion of the upswing until unutilized capacity has been brought into operation. However, since capacity increases more often than not during contractions and the early stages of expansions in growing industries, contractions are ordinarily brief in these industries, and temporarily "low" rates of utilization are not apt to have a severe depressing influence on longer-term expectations. Furthermore some projects originated during upswings may carry over into downswings. On the other hand the pressure of unutilized capacity is certainly felt during deep and prolonged depressions (Table 2).

The rates of utilization attained at the peaks of many of the peacetime cycles were well below the record wartime rates. Obviously greater rates of output could have been attained in those years by more intensive use of existing capacity. It may be objected that the earlier discussion stressed the relevance of cost-price relationships to the question of attainable rates of capacity utilization and that it is therefore incorrect to infer that surplus capacity existed at many of the peacetime peaks. However, that objection has little force since the acceleration principle posits a technological restraint on capacity utilization. Of course if the assumption of a rigid ratio of capital stock to output is not taken literally, it is quite possible that after some critical limit an increased rate of output will accelerate the growth of capacity even if a higher level of utilization is possible.

To test the latter hypothesis, scatter diagrams relating capacity change to the level of utilization were prepared, and it was found that higher levels of utilization tended to be associated with greater changes of capacity in growing industries (including industries experiencing mixed secular change). This tendency is illustrated in Table 7, which shows the average change of capacity (appropriately lagged) associated with low, medium, and high ranges of capacity utilization.[7] In every industry there was a substantial increase in the average rate of growth of capacity between the low and medium ranges of utilization and again between the medium and high ranges of utilization.

The low range of utilization includes most of the few years of disinvestment experienced by growing industries, which of course

[7]The lag for each industry was determined by inspection of scatter diagrams. Zero, one, and two-year lags were tried for each industry and the lag which yielded the least dispersion of the observations was chosen (see Appendix B for the ranges of utilization and the number of observations included in each range).

TABLE 7

Average Annual Capacity Change Associated with Low, Medium, and High Ranges of Capacity Utilization in Growing Industries[a], 1906–1951

(*units of each series*)[b]

Industry	Period Covered	Lag of Capacity Change Behind Capacity Utilization[c] (years)	Low Capacity Utilization: Average Change	Low Capacity Utilization: Average Deviation	Medium Capacity Utilization: Average Change	Medium Capacity Utilization: Average Deviation	High Capacity Utilization: Average Change	High Capacity Utilization: Average Deviation
By-product coke	1910–1949	1	1	3	18	10	28	19
Steel ingots	1914–1951	1	2.2	4.1	15.6	11.2	29.5	9.1
Petroleum refining	1917–1949	2	8.8	9.9	16.1	7.1	23.4	11.7
Electric power	1921–1951	2	42.2	32.6	174.8	38.3	385.7	155.3
Paper	1917–1950	0	12.2	18.6	61.0	23.4	100.4	52.9
Portland cement	1909–1949	2	−14.2	23.1	45.2	31.4	130.6	46.7
Electrolytic copper	1906–1949	1	−10	14	10[d]	22	46[e]	26
Pig iron	1913–1951	1	3.2	6.8	4.6	4.9	17.5	4.8

[a]See Appendix B for ranges of utilization and number of observations included in each range.
[b]See note a of Table 3 for units for each industry.
[c]The lag for each series was determined by inspection of scatter diagrams. Zero, one-year, and two-year lags were tried for each industry, and the lag which yielded the least dispersion of the observations was chosen.
[d]Excluding an extreme value for the year 1916. If the capacity change during 1916 is included, the average is 24 and the average deviation is 33.
[e]Excluding an extreme value for the year 1917. If the capacity change during 1917 is included, the average is 59 and the average deviation is 36.

Note: Includes industries experiencing mixed secular change of capacity, but excludes high explosives. The latter industry shows a slight tendency toward higher capacity change in higher utilization ranges (with a two-year lag), but that tendency cannot be described by averages for low, medium, and high ranges of utilization because of the influence of extreme values. The war years 1942–1946 are excluded from the averages for all industries.

considerably reduces the average rate of capacity change. However, capacity growth at a rate comparable to that typical of the medium range of utilization seldom occurs in the low range. The lower boundary of the medium range of utilization may be regarded as a level of utilization above which substantial capacity expansion is usually induced. This interpretation gains support from the fact that the high range of utilization in the by-product coke, steel, petroleum-refining, electric power, and paper industries includes primarily years of extraordinary demand associated with war and its aftermath.[6] The medium range of utilization is the more typical of normal peacetime conditions, and the increase in the average rate of capacity growth between the low and medium ranges may therefore be regarded as a significant acceleration of the rate of growth, representing the effect of cyclically induced investment.

These results show conclusively that there is a relationship between the level of utilization and the rate of growth of capacity—a relationship which is broadly consistent with the predictions of the modified acceleration principle. However, the evidence should be interpreted with caution. In the first place inspection of the scatter diagrams reveals a fairly regular tendency for the rate of capacity change to rise as utilization rises within the medium range of utilization. It is not as if output increased until it hit a definite limit of utilization which imposed a technical restraint on output unless capacity were expanded. Moderate levels of utilization induce moderate expansions of capacity despite the fact that a substantial margin of unused capacity still exists. Secondly there is considerable variability around the underlying relationship between utilization and capacity change, as the average deviations in Table 7 indicate.

These observations suggest that there is a fairly wide range of entrepreneurial choice involved in reactions to increased levels of output and utilization. Indeed that is also suggested by the theory of investment. The supply prices of assets, the availability and interest cost of funds, and the prospective yield of the investment

[6]The years 1942–1946 are not included in the averages. However, very few observations from the 1920's or 1930's are included in the high range of utilization of the industries listed above. The years typical of that range are 1916–1919, 1940–1941, and 1947–1951. The high range in Portland cement is almost completely dominated by the 1920's, a decade of intense construction activity. The high range in electrolytic copper includes most of the years of rapid growth during 1910–1918, and again most of the years 1925–1930. The early 1920's were years of low utilization and disinvestment as the industry absorbed the excess capacity created during World War I.

over its economic life must all be considered in investment decisions. Current and recent levels of capacity utilization presumably enter these calculations in two main ways: they provide part of the basis on which future levels of demand and output are estimated and they influence the relative costs of production with given and expanded facilities. If these influences are strong enough to produce the investment behavior predicted by the acceleration principle, the neglect of expectations and cost-price relationships in the application of the principle to cyclical phenomena is justified, otherwise it is not.

But what is the investment behavior predicted by the acceleration principle? The principle does not derive its force from the proposition that induced investment occurs during upswings but rather from the proposition that net real investment varies directly with the *rate of growth* of output. Thus far we have shown only that there is a relationship between the *level* of capacity utilization and the rate of change of capacity, but this finding is consistent with the hypothesis that induced investment is a function of the *level* of output. We turn now to consideration of the hypothesis that changes in the rate of growth of output induce changes in the rate of growth of capacity.

If changes in capacity always required changes in capital stock in a fixed proportion and if the level of utilization of capacity were constant, both changes in capacity and changes in capital stock would be proportional to changes in output, i.e. net real investment would vary directly and proportionally with the rate of change of output. It is clear from the data that the second condition does not hold and it is to be doubted on a priori grounds that the first condition holds. However, the acceleration hypothesis would still be a powerful tool if only the direction of change of net investment could be explained by it, and that could be true even if the foregoing conditions do not hold rigorously.[9]

Since the present data yield no information about the ratio of capital stock to output, they cannot be used to test for a direct relationship between net investment and the rate of change of output. Nonetheless the data can be used to establish whether changes in the rate of growth of output are associated with changes in the rate

[9]Indeed, in view of the rather long period that may be required to put new facilities in place, some change in capacity utilization must occur if a present increase in output is to induce a future expansion of capacity. That is, this must be true if the acceleration coefficient is applied to changes in output rather than to changes in the demand for output.

of growth of capacity in the same direction, and therefore whether the possibility exists that net real investment has changed in the predicted direction. In Table 8 we compare the directions in which the rates of growth of production and capacity changed during cyclical expansions in growing industries. Comparisons are made with three different lags and both including and excluding years in which capacity utilization was in the low range defined in Appendix B.

The comparisons yield mixed results. According to the acceleration principle, a decrease in the rate of increase of production should induce a decrease in the rate of increase of capacity, and vice-versa, so that the rates of change should consistently vary in the same direction. No such persistent relationship is discernible in the data, whether simultaneous rates of change are compared or lags are assumed. In either case there are numerous opposing movements. On the other hand in many industries the conforming movements outnumber the opposing movements by a considerable margin in the most "favorable" of the three sets of comparisons (zero, one-year, or two-year lag) so that some tendency toward the predicted behavior seems to be present.

Here we encounter a difficulty. In growing industries capacity increases almost continuously, but the magnitude of increase can and often does vary erratically from one year to the next. The same is true of the rate of change of production during cyclical expansions. Hence it is quite conceivable that at least one out of the three sets of comparisons would yield favorable results by chance. However, it will be recalled that in each industry one of the lags yielded superior results when the relationship between the level of utilization and the rate of capacity change was studied. Our confidence in the present comparisons would be increased if the same lag were again found to yield good results. That does occur in the by-product coke, paper,[10] high explosives, and electrolytic copper industries. The preponderance of conforming movements in the simultaneous comparisons for the petroleum-refining and electric power industries is probably due to chance since the true lags seem to be on the order of two years in those industries. A two-year lag yields the best results for steel ingots whereas a one-year lag was superior in the earlier test. The reverse is true

[10]The preponderance of conforming movements is even greater with a two-year lag in the paper industry, but the true lag appears to be quite short in that industry, and good results are obtained with the simultaneous comparison.

TABLE 8

Number of Years in Which the Rate of Change of Capacity Changed in the Same (+) or Opposite (–) Direction as the Rate of Change of Production During Expansions of Production in Growing Industries, 1907–1951

Industry	Period Covered[a]	Including Years of Low Utilization: Simultaneous Changes of Capacity and Production		Including: One-Year Lag of Capacity Change Behind Production Change		Including: Two-Year Lag of Capacity Change Behind Production Change		Excluding Years of Low Utilization[b]: Simultaneous Changes of Capacity and Production		Excluding: One-Year Lag of Capacity Change Behind Production Change		Excluding: Two-Year Lag of Capacity Change Behind Production Change	
		+	–	+	–	+	–	+	–	+	–	+	–
By-product coke	1910–1949	8	15	12	10	5	15	8	12	12	7	5	12
Steel ingots	1914–1951	9	12	5	14	11	6	8	10	5	11	9	5
Petroleum refining	1917–1949	14	7	11	10	6	14	11	5	9	7	5	10
Electric power	1921–1951	12	8	7	12	8	9	12	5	6	10	7	7
Paper	1917–1950	12	10	11	10	14	7	12	7	8	10	13	5
High explosives	1922–1951	7	9	5	9	7	5	6	8	4	8	6	4
Portland cement	1909–1932	6	8	9	5	6	8	6	7	8	5	6	7
Electrolytic copper	1907–1934	4	14	10	7	9	6	3	12	10	5	8	6
Pig iron	1913–1924, 1940–1951	5	7	5	5	5	3	5	6	5	4	4	3

[a]Excluding 1942–1946 in all industries.

[b]Excluding years in which capacity utilization was in the low range as defined in Appendix B.

Note: If capacity decreased, remained unchanged, or increased at the same rate as in the preceding year, it is counted as a change in the opposite direction to either an increase or decrease in the rate of increase of production.

in the case of Portland cement. Of course the true lag may be of intermediate length in those two industries. Finally none of the lags yields particularly favorable results for pig iron.

Perhaps these mixed results are all that may reasonably be expected. *Ceteris paribus*, a firm in a growing industry contemplating an expansion of capacity is likely to undertake a greater expansion if output has been increasing rapidly than if it has been increasing slowly. The rate of increase of demand and output in the recent past is part of the data on which an estimate of the rate of increase of demand and output in the future, and therefore the needed increase in capacity, will be based. It follows that there should be a tendency for an increase in the rate of increase of production to lead to an increase in the rate of increase of capacity and vice-versa. It also follows that there should be numerous exceptions to this pattern of behavior since capacity *can* be used more or less intensively and expectations are not rigidly linked to recent events.

Capacity and Capacity Utilization in War and Peace

It is difficult to generalize about the influence of war on capacity. Some industries will be stimulated and others retarded by war. Furthermore the rate of change of capacity during a war will be affected by the levels of capacity and capacity utilization which prevail at the beginning of the war, which, in turn, are related to the peacetime developments which precede the war. Again, the rates of change of capacity in a given industry during two widely separated wars will be affected by the stage of secular growth reached prior to each war, the composition of the national output during the wars, the degree of restraint on private action during the wars, etc. Given this diversity of influences, perhaps the major value of Table 9 is the light which it throws on the historical fortunes of particular industries.

Nonetheless it is possible to discern certain tendencies which the industries share in common. In six of the eight industries for which data are available for both world wars, the percentage rates of increase of capacity were greater in World War I than in World War II. However, in the case of two of the industries included in this group, the higher percentage rate of growth during World War I reflects the low base from which capacity increased—the absolute rate of growth of capacity was greater in World War II than in World War I in those industries. World War II accelerated the growth of capacity in ten of the thirteen industries, after the slow growth of

TABLE 9

Average Annual Changes of Capacity, 1899–1951

Industry	*Period Covered*	*Entire Period*	*Initial Year-1914*	*1914–1919*	*1919–1929*	*1929–1939*	*1939–1946*	*1946–Last Year*
ABSOLUTE CHANGES OF CAPACITY[a]								
A. Industries Experiencing Secular Growth of Capacity								
By-product coke	1910–1949	17	20	39	24	2	13	10
Steel ingots	1914–1951	16.5		32.6	10.5	9.5	14.1	29.7
Petroleum refining	1917–1949	15.8		11.3[b]	20.7	5.9	16.4	33.9
Electric power	1921–1951	172.6			172.0[c]	82.0	150.6	385.7
Paper	1899–1950[d]	42.5	24.4	24.6	60.3	28.5	55.2	101.5
High explosives	1922–1951	12.6			9.4[e]	3.8	30.6	9.1
B. Industries Experiencing Secular Decline of Capacity								
Beehive coke	1908–1949	−119	−13	−140	−282	−147	14	27
Wheat flour	1923–1951	−20.2			−1.1[f]	−20.9	1.7	−72.0
Cotton spinning	1922–1950	−12.6			−3.9[g]	−24.7	−8.6	−4.6
Black blasting powder	1922–1951	−89.4			−94.5[h]	−86.1	−112.7	−58.2
C. Industries Experiencing Mixed Secular Change of Capacity								
Portland cement	1909–1949	38.4	61.4	19.4	109.0	3.6	−20.6	49.9
Electrolytic copper	1906–1949	24	41	102	13	8	−2	−1
Pig iron	1913–1951	6.3		12.0	1.9	−1.6	15.0	13.2
PERCENTAGE CHANGES OF CAPACITY[i]								
A. Industries Experiencing Secular Growth of Capacity								
By-product coke	1910–1949	19.5	23.3	23.6	6.5	0.4	2.1	1.4
Steel ingots	1914–1951	3.6		7.2	1.7	1.3	1.7	2.0
Petroleum refining	1917–1949	13.3		9.6[b]	14.6	1.7	4.0	6.5
Electric power	1921–1951	15.0			15.0[c]	3.2	4.5	8.8
Paper	1899–1950[e]	15.3	8.8	3.8	7.9	2.1	3.3	5.0
High explosives	1922–1951	2.7			2.0[e]	0.7	5.4	1.2
B. Industries Experiencing Secular Decline of Capacity								
Beehive coke	1908–1947	−2.1	−0.2	−2.5	−5.7	−7.0	2.2	3.6
Wheat flour	1923–1951	−1.0			−0.1[f]	−1.0	0.1	−4.0
Cotton spinning	1922–1950	−1.3			−0.4[g]	−2.6	−1.2	−0.7
Black blasting powder	1922–1951	−2.8			−3.0[h]	−3.5	−7.1	−7.2
C. Industries Experiencing Mixed Secular Change of Capacity								
Portland cement	1909–1949	3.7	6.0	1.4	7.6	0.1	−0.8	2.1
Electrolytic copper	1906–1949	4.3	7.4	11.5	0.9	0.6	−0.2	−0.1
Pig iron	1913–1951	1.2		2.4	0.3	−0.3	2.7	2.3

Notes on next page

Notes to Table 9

[a]Total change of capacity between the initial and final years of each period, divided by the number of years in the interval. See note a of Table 3 for units for each industry.

[b]1917–1919.

[c]1921–1929.

[d]Estimates of paper capacity are available at five-year intervals, 1899–1914. These estimates were not used in the other tables.

[e]1922–1929.

[f]1923–1929.

[g]1922–1929.

[h]1922–1929.

[i]Total percentage change of capacity between the initial and final years of each period, divided by the number of years in the interval.

the depression decade.[11] In contrast, capacity grew more slowly during World War I than in the preceding peacetime interval in three of the five industries for which data are available, although it would not do to rest much weight on this limited number of observations.

As far as peacetime changes of capacity are concerned, the rates of growth of capacity during the prosperous 1920's were almost universally greater than in the depression decade that followed. A great majority of the industries experienced a greater rate of growth in the interval after World War II than in the depression decade, and several others grew more rapidly after 1946 than in either the 1920's or 1030's. Of course these high rates of postwar growth are for intervals of only three to five years whereas the earlier averages cover periods of ten years.

During World War II ten of the thirteen industries attained higher levels of capacity utilization than in any previous peacetime year (Table 10). It is evident that, under the pressure of war demand, capacity utilization can be extended substantially beyond the normal peacetime levels, although perhaps at considerable cost as marginal capacity is tapped.[12] Capacity was not utilized as intensively during World War I. Seven of the eight industries for which data are available operated at higher peak rates of utilization in World War II than in World War I and four of them exceeded the World War I rate of utilization during the 1920's. The peak war rates did not all come at the same time in either war, but many came early in both wars.

[11]This comparison and those which follow count a slower rate of decline as an acceleration of the rate of growth.

[12]It is interesting to note in this connection that several of the industries attained even higher rates of utilization after World War II.

TABLE 10

Highest Ratios of Capacity Utilization[a] and Years of Attainment, 1906–1949

(per cent)

Industry	Period Covered	Pre-World War I Year	Pre-World War I Ratio	World War I Year	World War I Ratio	1920's Year	1920's Ratio	1930's Year	1930's Ratio	World War II Year	World War II Ratio	Post-World War II Year	Post-World War II Ratio
A. Industries Experiencing Secular Growth of Capacity													
By-product coke	1910–1949	1912	86.8	1916	88.3	1929	89.2	1937	78.8	1942	98.0	1947	93.0
Steel ingots	1915–1949			1916	89.7	1929	87.5	1937	71.5	1943	96.6	1948	93.1
Petroleum refining	1917–1949			1917	72.8	1925	80.2	1939	83.4	1944	93.3	1948	92.3
Electric power	1921–1949					1923	39.2	1937	38.4	1943[b]	53.5	1948	59.1
Paper	1917–1949			1918	82.9	1920	84.1	1936	82.8	1941	95.9	1947	95.9
High explosives	1922–1949					1926	68.0	1939	59.2	1942	81.0	1948	85.7
B. Industries Experiencing Secular Decline of Capacity													
Beehive coke	1908–1949	1913	58.7	1916	64.5	1923	52.0	1937	43.2	1942	80.6	1947	85.9
Wheat flour	1923–1949					1929	57.2	1939	58.4	1945	76.5	1947	85.5
Cotton spinning	1922–1949					1929	103.6	1937	133.3	1943	200.2	1948	193.0
Black blasting powder	1922–1949					1923	50.6	1936	42.3	1945	44.6	1948	44.8
C. Industries Experiencing Mixed Secular Change of Capacity													
Portland Cement	1909–1949	1913	70.2	1916	65.8	1923	86.5	1930	62.4	1942	73.7	1949	81.7
Electrolytic copper	1906–1949	1909	92.7	1916	95.5	1929	94.4	1930[c]	71.5	1941	92.9	1947	82.3
Pig iron	1913–1949	1913	70.1	1916	85.9	1929	82.2	1937	73.0	1942	96.5	1947	88.6

[a]Capacity utilization is measured by the ratio of production to capacity.
[b]Also attained in 1944.
[c]Also attained in 1937.

APPENDIX A

List of Capacity Series and Their Principle Characteristics

1. Beehive coke, 1908–1949

   Source: 1908–1930, E. G. Nourse and associates, *America's Capacity To Produce*, Brookings Institution, 1934; 1931–1949, *Minerals Yearbook*, Bureau of Mines, 1949.

   Unit: Tons. The basic data are number of ovens. The number of ovens is multiplied by 590 tons to derive the capacity estimate. "This (590 tons) is a fair measure of the annual capacity of the standard beehive coke oven" (Nourse, *op. cit.*, p. 65). A later (confidential) source states that the average oven size may have declined since 1929. However, an estimate of capacity in 1940 made by other means corresponds closely to the figure derived from the assumption of an average oven capacity of 590 tons.

   Principal Characteristics: Includes idle ovens. "In 1929 the capacity of idle plants was 9.3 million tons, or 44 percent of the aggregate capacity operating and idle" (Nourse, *op. cit.*, p. 65). Nourse gives an estimate of 5 per cent as the discount for repairs and plant disability. Mean annual beehive coke capacity has declined from a peak of 59 million tons in 1910 to 8.2 million tons in 1949, as the beehive oven has been displaced by the more efficient by-product oven. "The present-day importance of this type of equipment lies chiefly in its ability to provide a quick and inexpensive means of producing coke to meet peak demands" (*Minerals Yearbook*, 1949, p. 415).

2. By-product coke, 1910–1949

   Source: 1910–1930, Nourse, *op. cit.*; 1931–1949, *Minerals Yearbook*, 1949.

   Unit: Tons

   Principal Characteristics: "The basis for calculating the potential annual coke capacity of a plant is the minimum coking time necessary to produce a coke with the qualities suitable for its intended use. For this reason, the potential capacity of a plant is subject to change from year to year, depending on the age and condition of ovens, character and quality of coal charged, type of coke required, and other related economic conditions. . . . It is believed, however, that the potential capacity . . . is a good measure of the practical operating capacity" (*Minerals Yearbook*, 1949, p. 417). The manufacture of by-product coke is a continuous process. Nourse estimates a 5 per cent discount for "scurfing of ovens, repairs, and plant disability" (Nourse, *op. cit.*, p. 553). Mean annual by-product coke capacity (including idle plants) has increased from 8.6 million tons in 1910 to 74.1 million tons in 1949.

3. Pig iron, 1913–1951
Source: Annual Statistical Report, American Iron and Steel Institute.
Units: Tons
Principal Characteristics: Rated capacity of blast furnaces. Does not include blast furnaces which have long been idle. Continuous operation. "...it will be seen that the concept of capacity in blast furnaces is a rather elastic one. During the war [World War I], for example, it was possible, by drawing on plants which under other circumstances would have been regarded as obsolete and by operating for unusual stretches of time without relining or other repairs, to run for some months at well above normal practical capacity" (Nourse, *op. cit.*, p. 256).

4. Steel ingots, 1914–1951
Source: Annual Statistical Report, American Iron and Steel Institute.
Unit: Tons
Principal Characteristics: Rated capacities of various types of equipment: open hearth, Bessemer, crucible, electric. Does not include long idle plants. Continuous operation.

5. Electrolytic copper, 1906–1949
Source: 1906–1929, Nourse, *op. cit.*, p. 557; 1931–1945, *Yearbook of the American Bureau of Metal Statistics*, various issues; 1946–1950, *Metal Statistics*, American Metal Market, 1951.
Unit: Tons
Principal Characteristics: Reported annual capacity of plants in operation. Nourse places deduction for unavoidable breakdowns at 3 per cent (Nourse, *op. cit.*).

6. Petroleum refining, 1917–1949
Source: 1917–1930, Nourse, *op. cit.*, p. 556; 1931–1949, *Minerals Yearbook*, various issues.

Unit: Barrels of crude run to stills. The rated daily capacity is multiplied by 365.

Principal Characteristics: Rated capacity of operating plants. Nourse estimates a discount of 4 per cent for seasonal variation and 10 per cent for both seasonal variation and shutdowns for necessary cleaning and repairs. Continuous operation.

7. Portland cement, 1909–1949

Source: 1909–1930, Nourse, *op. cit.*, p. 473; 1931–1949, *Minerals Yearbook*, various issues.

Unit: Thousands of barrels

Principal Characteristics: Rated capacity. Includes allowance for breakdowns. Nourse places allowance for seasonal variation at 17 per cent. Continuous operation.

8. Electric power, 1920–1951

Source: Statistical Bulletin, Edison Electric Institute, 1951, pp. 16–20.

Unit: Kilowatt-hours. Rated capacity in kilowatts is multiplied by 8,760 hours (number of hours in year). A multiplier of 8,784 hours is used for leap years.

Principal Characteristics: Rated capacity of generators. Continuous operation. Very large seasonal variation.

9. Paper, 1917–1950

Source: Statistics of the Paper Industry, 1951, American Paper and Pulp Association, p. 53.

Unit: Tons. Capacity measured on a tons-per-day basis is multiplied by 310 days to estimate annual capacity. Daily output is calculated for a 24-hour day with an allowance for normal cleanup.

Principal Characteristics: Continuous operation. Capacity is defined as the maximum amount of paper that can be produced by a given set of equipment based on normal expectations of grade and weight expected to be produced.

10. Wheat flour, 1923–1951

Source: 1923–1944, *Wheat Ground and Wheat Milling Products*, Bureau of the Census; 1945–1951, *Facts for Industry Series*, M-16A.

Unit: Barrels. Annual capacity figures obtained by averaging monthly data of daily (24-hour) capacity to obtain average daily capacity and then multiplying this figure by the number of working days in the year (306 during 1923–1948, and 255 from 1949 forward).

Principal Characteristics: Rated capacity. Continuous operation except that small mills usually operate in the daytime only. The mills covered in the data produced about 85 per cent of the flour reported in 1923–1924 and 90 to 95 per cent of the flour reported thereafter.

11. Cotton spinning, single-shift basis, 1922–1950, double-shift basis, 1934–1950

Source: Cotton Production and Distribution, Bureau of the Census, various issues.

Unit: Spindle-hours. No capacity data are published. However, the number of spindle-hours run is published, as is a monthly utilization ratio. The capacity figure has been derived by dividing spindle-hours by the utilization ratio. The data were published on a single-shift basis through 1938 and a double-shift basis after 1933. The published single-shift data (1922–1938) have been extended through 1950. The average ratio of the activity ratios on the single-shift and double-shift basis, which overlap for the period 1934–1938, was applied to the published double-shift data after 1938.

Principal Characteristics: Capacity does not define an upper limit. The number of spindles installed has declined from a peak of 37.9 million in 1925 to 23.0 million in 1950, but the extension of multiple-shift operation has led to a more than proportional increase in hours run per spindle. The highest number of spindle-hours operated before World War II was 102.6 billion (1927). In 1950 the figure was 116.1 billion.

12. Permissible and other high explosives, 1922–1951

Source: 1922–1943, *Technical Paper 665*, Bureau of Mines, 1944–1951, by letter from the Bureau of Mines.

Unit: Pounds. The daily output that can be prepared ready for shipment during one daytime shift of 8 hours is multiplied by 300 days to estimate annual capacity.

Principal Characteristics: Rated capacity of operating plants reporting to Bureau of Mines. Nourse estimates discount for seasonal variation as 20 per cent. Does not include military explosives (Nourse, *op. cit.*).

13. Black blasting powder, 1922–1951.

Source: Technical Paper 665, as cited.

Unit: Pounds. The daily output that can be prepared for shipment during one 24-hour day is multiplied by 300 days to estimate annual capacity.

Principal Characteristics: Rated capacity of operating plants reporting to Bureau of Mines. Nourse estimates seasonal discount as 24 per cent (Nourse, *op. cit.*).

APPENDIX B

Ranges of Capacity Utilization[a] and Number of Observations Included in Each Range in Table 7

(per cent)

	Low Capacity Utilization		*Medium Capacity Utilization*		*High Capacity Utilization*	
Industry	*Range*	*Observations*	*Range*	*Observations*	*Range*	*Observations*
By-product coke	33–54	7	65–85	18	86–93	9
Steel ingots	19–48	7	58–79	14	80–95	11
Petroleum refining	63–69	8	70–79	11	80–91	7
Electric power	26–34	7	35–40	12	50–59	5
Paper	58–74	8	75–84	15	85–99	6
Portland cement	23–56	12	62–68	14	70–86	8
Electrolytic copper	22–58	12	66–79	11	80–95	13
Pig iron	17–58	10	60–79	16	81–91	7

[a]Utilization is measured by the ratio of production to capacity.

COMMENT

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Bert G. Hickman has performed an extremely useful task in assembling and analyzing a substantial body of evidence bearing on the empirical usefulness of the "acceleration hypothesis" in explaining fluctuations in investments.

This hypothesis, which represents one of the cornerstones of many of the recently developed analytical models of the business cycle, has been seriously challenged of late and most recently by Arthur F. Burns in his well-known review of J. R. Hicks' book.[1] In this review, which directly criticizes Hicks' work and indirectly a much larger class of business cycle theorists, Burns has emphati-

[1]J. R. Hicks, *A Contribution to the Theory of the Trade Cycle*, London, Oxford University Press, 1950; Arthur F. Burns, "Hicks and the Real Cycle," *Journal of Political Economy*, February 1952, pp. 1–24.

cally questioned, if not explicitly denied, the empirical usefulness of the acceleration mechanism in business cycle analysis: "...the accelerator of Hicks's model is supposed to do its work in successive short periods, and I do not think it can be trusted for this purpose" (pages 11–12); there isn't "...any substantial statistical support for the acceleration principle, taken as a general theory of investment in fixed capital over the business cycle" (page 13); ". . . practically all of it [investment in plant and equipment] is 'autonomous,' practically none of it is 'induced'" (page 14); "...it will not do to treat investment as a technical echo of the changes in past output" (page 18); etc.

In this light, Hickman's contribution in bringing together and analyzing a substantial body of historical data acquires particular significance. There may be some doubts as to whether his data are quite as adequate as he seems to think for a conclusive test of the acceleration principle. But, as I shall try to point out in this comment, such tests as can be carried out from Hickman's data fully support the acceleration hypothesis *properly understood and formulated* and confirm that this hypothesis is a very useful principle in explaining much of the behavior of investment in fixed capital.

The above conclusion is not inconsistent with the many negative results reported by Hickman because a major portion of his paper is devoted to destroying a straw man. I submit that most of the economists who, in recent years, have regarded the acceleration mechanism as a useful component of business cycle theory have in mind a model which is only faintly related to the one Hickman seems to be testing in the first five of his seven tables devoted to such tests. As I shall try to show, it is only in his Table 7 that he comes reasonably close to a relevant test.

The first point to bear in mind is that the acceleration principle is a statement about the behavior of net capital outlays while Hickman's data relate to net changes in capacity. Now, the outlays (or the employment of resources) required to bring about an addition to capacity will tend to occur over a span of time while the actual addition to capacity will tend to be concentrated at the end of the span in question. It is clear, therefore, that in general net investments and net changes in capacity over an arbitrary interval of time, such as a year, need not bear a stable relation to each other. Suppose, for instance, that in a given industry there is an average span of, say, two years between the time the construction of new capacity gets under way and the time the new capacity is completed and ready to operate. Then, clearly, investment outlays in any year will partly be devoted to completion of projects started in the previous year which will add to capacity this year, and partly to starting new projects which will generate additional capacity only next year. Thus, while current investment may react with a short lag to an increase in output and may depend on the behavior of output over several previous periods,[2] the current increase of capacity may be related to the behavior of output over a more limited and substantially lagged period of time. Similarly in the presence of excess capacity, investment outlays of the type required to maintain capacity in efficient operating condition may decline, and yet there may be no formal retirement of capacity of the type recorded in Hickman's data.

This does not mean that Hickman's data are useless in testing the acceleration hypothesis; quite the contrary, his series are in many respects more tractable than investment data in testing the functioning of this mechanism. It does mean, however, that the model to be tested has to be adjusted so that it will apply to capacity data—and to individual industries rather than to the economy as a whole.

Such a model can be readily constructed starting from the type of formulation underlying, say, Hicks' construction—and would run something like this.[3]

Assumptions:

1. For a given industry, and for every rate of output, there exists, at any point of time t, an *optimum* or desirable level of capacity which, as a first approximation, may be regarded as proportional to output. Denoting by $\bar{K}$ this optimum level of capacity and by O the rate of output, this hypothesis can be stated as[4]

$$\bar{K} = a_t O \tag{1}$$

The proportionality factor a is characterized by a time subscript since in principle it may vary over time depending on a host of factors, some of which will be mentioned later.

2. For a given industry there exists a typical and reasonably stable span elapsing between the time decisions to increase ca-

[2]See Hicks, *op. cit.*, Appendix to Chapter V.

[3]See e.g. Hollis B. Chenery, "Overcapacity and the Acceleration Principle," *Econometrica*, January 1952, pp. 1–28; R. S. Eckaus, "The Acceleration Principle Reconsidered," *Quarterly Journal of Economics*, May 1953, pp. 209–230.

[4]Following Hickman, we shall measure capacity, K, of a given industry as the flow of output per unit of time obtainable from the existing facilities. Hence K has dimension (output)/(time), while a is a pure number.

pacity are reached and the time the additional capacity is actually installed and ready to operate. We shall denote this lag by g.

3. Whenever there is a prospective "shortage" of capacity in the sense that the capacity on hand (or already under construction) is below the level that is optimal to produce the output expected to be demanded g periods later, expansion of capacity will get underway; and the *rate* of expansion will be roughly proportional to the size of the prospective shortage.

Denote by $O_{t-g}^{(t)}$ the rate of output that, at time $t-g$, is expected to prevail at time t. If we are dealing with annual data on capacity, K, and output (as Hickman does), then the three stated hypotheses lead to an equation of the form

$$\Delta K_t = K_t - K_{t-1} = \beta(a_{t-g} O_{t-g}^{(t)} - K_{t-1}) \tag{2}$$

provided

$$a_{t-g} O_{t-g}^{(t)} > K_{t-1} \tag{2a}$$

Here the constant β (with dimension 1/time) measures, primarily, the speed with which a given industry endeavors to make up deficiencies in capacity. For instance, if the unit of time were a year, a value of 0.5 for β would mean that the industry tends to make up such deficiencies at the rate of 50 per cent per year. Clearly the numerical value of β depends on the choice of the time unit, i.e. the interval over which we measure the growth of capacity; we should expect this coefficient to be a proper fraction if we are dealing with short intervals[5] and to approach unity as the interval lengthens. (It may be noted that if g is larger than one, K_{t-1} is not the same thing as the capacity actually on hand at the time the expansion decision occurs, but represents rather an approximate measure of the capacity then on hand and under construction. In fact, in view of the definition of g, capacity on hand at time $t-1$ must be either on hand or already in progress at time $t-g$. It is possible, of course, to set up our model in terms of K_{t-g}; however, the formulation of equation 2 is the most convenient for our present purposes even if it is not the most refined.)

4. Finally it is assumed that under normal conditions the expected rate of output $O_{t-g}^{(t)}$ can be approximated reasonably well in

[5]Cf. Hicks, *op. cit.*, p. 40.

terms of the rate of output prevailing in the neighborhood of the time at which the expectation is held;[6] i.e. that

$$(3) \qquad O_{t-g}^{(t)} = \eta O_{t-g}$$

The coefficient η should be close to unity and is assumed reasonably stable over time; it may not be exactly unity, however, as it may be affected by the long-run growth of the industry and the value of g, and for this reason it may also be subject to some gradual drift over time.[7]

Substituting equation 3 into equation 2 yields a hypothesis which, aside from the parameters, involves only observable data of the type used by Hickman, namely

$$(4) \qquad K_t - K_{t-1} = \beta(a_{t-g}\eta O_{t-g} - K_{t-1})$$

provided

$$(4a) \qquad a_{t-g}\eta O_{t-g} > K_{t-1}$$

If the condition 4a does not hold, then the acceleration principle has very little to tell us as to what will happen to *capacity* except that it should tend to decrease as worn-out or obsolete facilities are retired and not replaced.[8] But since the rate at which capacity is retired depends on many factors, including the age distribution of existing facilities, we should not expect any very close relation between the amount of excess capacity at time $t-g$, namely $a_{t-g}O_{t-g} - K_{t-1}$, and the amount of plant actually retired in the course of the year t.

Most of Hickman's analysis does not test our equation 4. Rather it tests the hypothesis, which I shall label the "naive" acceleration model, according to which addition to capacity is proportional to the rate of change of output or,

$$(5) \qquad K_t - K_{t-1} = a(O_t - O_{t-1})$$

This naive model can be gotten out of our models 4 and 4a but only by introducing some further very special assumptions.

Assumptions:

5. β is unity, i.e. firms act instantaneously, or at least within a year (which is the time unit of Hickman's data) to wipe out *fully* any unbalance in capacity.

[6] *Ibid.*, p. 39.
[7] Cf. footnote 14.
[8] Cf. Hicks, *op. cit.*, p. 44.

6. g is zero, i.e. such actions aimed at adjusting capacity can produce the desired result, so to speak, overnight; or alternatively firms, having perfect foresight, are able at time $t-g$ to predict O_t accurately.

7. Propositions 5 and 6 hold when capacity is too large as well as when it is short.

8. a is constant over time.

Under these conditions equations 4 and 4a reduce to

$$K_t - K_{t-1} = aO_t - K_{t-1}$$

This equation in turn implies

$$K_t = aO_t$$

(capacity is always optimally adjusted to current output) and therefore, finally, the "naive" model

$$K_t - K_{t-1} = aO_t - aO_{t-1} = a(O_t - O_{t-1})$$

From a glance at the list of preposterous assumptions 5 to 8 which lead up to equation 5, one can hardly be surprised if Hickman's extensive tests show that this hypothesis is not well supported by the data. If anything, one may be rather astonished to find that, even in this untenable formulation, the acceleration principle is of some moderate help in explaining the behavior of capacity. His Table 1 shows that, while capacity did not move in the same direction as output every year, it did so for nearly two-thirds of the nearly 450 observations. Nor is Hickman's attempt at showing that this agreement is entirely explained by long-term trend completely convincing. For one thing a close examination of panel C of his table will reveal that the so-called "secular declines" of the industries with "mixed" trends are indeed hardly more than cyclical developments connected with the depression of the 1930's and prolonged by wartime restrictions of output or investments.

A second model tested by Hickman in panel B of Table 1 is obtained by relaxing assumption 6 and recognizing that g may be different from zero, but retaining the other assumptions. This leads to an equation of the form

$$(6) \qquad K_t - K_{t-1} = a(O_{t-g} - O_{t-g-1})$$

where g is presumably related to the length of time intervening between decision to change to capacity and the carrying out of this decision. In his table Hickman has reported results only for a value of $g = 1$ and these results represent indeed a slight improvement (especially for the critical industries with mixed trends). There is of course no reason why g should have the same value for all industries or why it should be the same when the desired change in capacity is up as when it is down. However, it is on the whole fortunate that no further efforts were spent by Hickman in testing the naive acceleration model, for such efforts would have been largely wasted.

If we want to carry out a meaningful and reasonably conclusive test of the usefulness of the acceleration principle, it is the model of equation 4 that needs to be tested. I do not wish to claim of course that every supporter of the acceleration mechanism would agree in every detail with the model I have set up or with the specific hypothesis I have used in deriving it. But I am quite confident that most of them would agree that, as long as this model, or some reasonable variation thereof, passes the empirical test, the usefulness of the acceleration principle in business cycle models is substantially vindicated.

It may be objected at this point that our model 4 looks pretty different from the formulation to be found, say, in Samuelson[9] or Hicks. But the difference is, in reality, more one of appearance than of substance. As I have tried to show, it results from spelling out in greater detail what was implicit in the broad formulation, in order to adjust the model to Hickman's type of data. As a matter of fact it can readily be shown that if our equation 4 is inserted, say, in Samuelson's classical model with but slight modifications, or in Hicks' formal structure, the implications of these models are substantially unchanged.[10]

[9] "Interaction Between the Multiplier Analysis and the Principle of Acceleration," *Review of Economic Statistics*, May 1939.

[10] To illustrate this point, take, for instance, Samuelson's model and make consumption a function of current income. His first two equations can then be written as (a) $Y_t = C_t + I_t$ and (b) $C_t = aY_t$. Next, representing by γ the cost of increasing capacity by one dollar per unit of time, we can write $I_t = \gamma(K_t - K_{t-1})$ where K_t denotes the capacity of the economy as a whole (measured in dollars per unit of time) and γ, with dimension time, corresponds to the usual notion of the acceleration coefficient. Making now use of our equation 4, taking $g = 1$, and remembering that for the entire economy output, O, can be replaced by income, Y, we obtain in place of Samuelson's acceleration equation the following expression (c) $I_t = \gamma\beta(aY_{t-1} - K_{t-1}) = bY_{t-1} - cK_{t-1}$. Since a is a pure number, both the coefficient $b = \gamma\beta a$ and $c = \gamma\beta$ are dimensionless, as noted in the text.

By substituting in equation (a) and carrying out appropriate manipulations, one can readily derive from these three equations the second-order difference equation (d) $Y_t = \{1 + [b/(1-a)] - c\} \; Y_{t-1} - [b/(1-a)] \; Y_{t-2}$.

At the same time the explicit introduction of the notion of the "speed of adjustment" in the formulation of the acceleration principle may be quite helpful in clarifying certain points connected with the choice of the time unit which are apt to lead to confusion. Briefly the issue is this: as is well known, the acceleration coefficient (or capital coefficient) has dimension time and therefore its numerical value depends on the unit of measurement for time. Now, in the models based on the acceleration principle, the value of the acceleration coefficient typically turns out to play a critical role in determining whether the time path of aggregate output will be damped or explosive. It would appear therefore that the stability implications of a given model can be changed by the purely formal trick of changing the choice of the time unit. Once we introduce our "speed of adjustment" coefficient, this disturbing possibility tends to disappear in that the stability of the system will generally depend on the product of this coefficient and the conventional acceleration coefficient and this product is *independent* of the choice of the time unit (since the speed of adjustment has dimension 1/time).[11]

The above remarks have the further implication that a slow speed of adjustment would tend to exert a stabilizing influence on the behavior of economic activity. This implication is, of course, not surprising when one considers that a gradual adjustment reflects the willingness of firms to tolerate short-term variations in the rate of utilization of capacity, partly absorbing the shock of variations in the flow of demand.

Hickman has not tested directly the model of equations 4 and 4a, but his test of Table 7 comes reasonably close to doing so. This can best be seen by dividing both sides of equations 4 and 4a by K_{t-1}, which yields the equation

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If we increase the value of g or change the lag in the consumption function, we merely get a difference equation of higher order; if we further take into account the irreversibility of our equation 4a, add autonomous investments and ceiling, we are back at Hicks' model.

[11]The notion of speed of adjustment can also be usefully introduced in connection with inventory behavior, where the acceleration coefficient is represented by the desired stock-sales ratio. This was actually done in a previous joint contribution with Owen H. Sauerlender in which, among other things, an attempt was made at securing a quantitative estimate of this parameter (see Franco Modigliani and Owen H. Sauerlender, "Economic Expectations and Plans of Firms in Relation to Short-Term Forecasting," *Short-Term Economic Forecasting*, Studies in Income and Wealth, Volume Seventeen, Princeton University Press for National Bureau of Economic Research, 1955, pp. 261–361, especially section 7).

$$\frac{K_t - K_{t-1}}{K_{t-1}} = \beta\eta a_{t-g} \frac{O_{t-g}}{K_{t-1}} - \beta \tag{7}$$

provided

$$\frac{O_{t-g}}{K_{t-1}} > \frac{1}{\eta a_{t-g}} \tag{7a}$$

To see the implications of equation 7, suppose that the "capital coefficient" a is approximately constant over the period of observation and that $g = 1$; then the first term on the right side of 7 can be written as $A(O_{t-1}/K_{t-1})$, where $A = \beta\eta a$ is some constant and O_{t-1}/K_{t-1} represents the rate of utilization of capacity lagged one year. In this form 7 says that the proportional growth of capacity in any given year is an increasing linear function of the lagged rate of utilization of capacity, provided 7a is satisfied, i.e. provided the rate of utilization of capacity is above a certain critical level. Below this level we should simply expect capacity to tend to decline (or stay constant) but without any close association to the actual rate of utilization.

The hypothesis actually tested by Hickman in Table 7 differs from equation 7 in the following respects: (a) a is assumed constant over time for all industries, (b) on the left-hand side the "percentage" change of capacity is replaced by the amount of change, $K_t - K_{t-1}$, (c) only integral values of g have been tested, and (d) for those industries for which g is different from unity the quantity O_{t-g}/K_{t-1} is replaced by O_{t-g}/K_{t-g}. It is clear that these differences, which arise from the failure of Hickman to test a well-defined basic model, are not overwhelming, so that the results of his test do shed some tentative light on the tenability of hypothesis 7.

It is apparent from Table 7 that our model stands up pretty well under this approximate test. For every industry included, the average annual increase of capacity rises from a near zero or negative figure corresponding to low levels of utilization to a much higher positive figure corresponding to high levels of utilization.

One may wonder at this point how the model of equation 7 would fare under a more direct test in which assumptions a to c are eliminated. A partial answer to this question is provided in the table below; the answer is only partial because the elimination of some of the shortcomings of Hickman's test would require much more extensive work than would be warranted for the purpose of this modest comment.

TABLE 1

A Test of the "Acceleration Hypothesis" for Hickman's Data: Yearly Percentage Change in Capacity in Relation to the (Lagged) Rate of Utilization of Capacity, 1908-1951

Industry and Period	Lag (years)	Rate of Utilization (per cent)	Number of Years in Which the Change in Capacity Was: Negative	0 to 1 per cent	Over 1 per cent	Percentage Yearly Change in Capacity: Mean	Average Deviation
Pig iron		Less than 60	6	5	0	−0.5	0.9
1915–1951	1	61–79	3	4	7	0.8	0.8
		80 and over	0	0	8	2.9	0.8
Steel ingots		Less than 50	4	2	0	0.2	0.5
1916–1951	$1\frac{1}{2}$	51–69	2	1	6	1.1	1.0
		70 and over	0	0	16	4.1	1.5
Electrolytic		Less than 70	12	4	0	−0.7	1.0
copper	$1\frac{1}{2}$	71–79	2	3	3	1.1	1.4
1908–1949		80 and over	0	0	11	6.0	1.8
Petroleum		Less than 70	2	0	4	1.2	2.3
refining	$1\frac{1}{2}$	71–80	2	0	5	4.6	3.3
1925–1949		81 and over	0	0	7	5.2	2.3
By-product		Less than 54	4	0	0	−0.4	0.2
coke	$1\frac{1}{2}$	55–78	2	3	5	1.2	1.2
1921–1949		78 and over	0	2	8	3.6	2.3
Paper		Less than 64	1	1	0	−0.9	0.9
1919–1950	$\frac{1}{2}$	65–75	0	2	3	1.8	1.2
		76 and over	1	0	20	5.3	2.3
Portland		Less than 50	7	2	1	−0.9	0.7
cement	$1\frac{1}{2}$	51–64	2	1	6	1.7	1.7
1911–1949		65 and over	0	0	16	5.0	2.7
High		Less than 49	1	2	2	0.1	2.8
explosives[a]	2	50–62	2	2	3	0.8	1.5
1924–1951		63 and over	2	0	6	1.9	1.6
Black blast-		Less than 42	12	1	5	−5.2	8.3
ing powder	$1\frac{1}{2}$	Over 42	2	0	3	2.1	3.7
1924–1951							
Beehive coke		Less than 62	27	1	3	−4.9	6.4
1909–1949	$1\frac{1}{2}$	Over 62	1	0	3	1.7	2.9

[a]Excludes 1940, 1947, and 1948 (see text).

In order to prepare our Table 1, scatter diagrams were made just like those described by Hickman, but with certain modifications discussed below:

1. As the dependent variable we have used the percentage change in capacity and as the independent variable the quantity O_{t-g}/K_{t-1}, as required by equation 7.

2. In addition to integral lags, also lags of one-half and one and one-half years were considered, when this appeared desirable from the data and other considerations.[12]

3. The years of "infancy" of the industry, if any were covered by the data, were eliminated. In these years growth does not reflect the acceleration mechanism but primarily the gradual establishment of the industry; in other words in Hicks' language we are dealing here not with acceleration-induced investment but, essentially, with autonomous investments. There were only two industries, and a few years, for which such an elimination appeared indicated. Specifically we eliminated, for beehive coke, the years 1912–1920 in the course of which output increased some three and one-half times, and, for petroleum refining, the years 1918–1924, during which output approximately doubled. It should be noted that, had these observations been included, our table would still show that the rate of addition to capacity increases with the lagged rate of utilization since in these years the rate of utilization was, of course, generally high. However, the inclusion of these observations would have considerably distorted the figures of the table by giving an exaggerated impression of the rate of growth at high levels of utilization.

4. The scatter diagram for each industry was examined for evidence of significant trends in a, the desirable rate of utilization of capacity; clearly, if such a trend is present, the scatter diagram has to be replaced by a more elaborate one. A marked rising trend in the desirable rate was found for electric power. This result was expected on the basis of a nearly completed intensive study of investment in this industry carried out jointly with Avram Kisselgoff. Incidentally, this study partly inspires this comment. Because of the problems created by this trend and because this industry will be thoroughly covered in the above-mentioned study, our table excludes electric utilities. It will suffice to indicate at this point that the above-mentioned trend can be readily explained in terms of technological and other changes and that our study finds impressive evidence of the working of the accelerator mechanism for this in-

[12]When the lag is, say, one and one-half years, the dependent variable should be $O_{t-(3/2)})/K_{t-1}$ which, with the data available, could be approximated by $(O_{t-1} + O_{t-2})/2K_{t-1}$; for reasons of computational expediency the approximation actually used was $\frac{1}{2}[(O_{t-1}/K_{t-1} + O_{t-2}/K_{t-2})]$. Since K_t typically changes very slowly from year to year, this approximation cannot significantly distort the results and can be defended also on other grounds. A similar procedure was used for testing half-year lags, which was done only for the paper industry.

dustry.[13] Some evidence of an increasing trend in the optimum rate was also found for petroleum refining, and this finding too seems to be supported by the technological history of this industry. However, since this trend was not marked after the first few years, which had been eliminated anyhow, the figures presented in Table 1 are based on the assumption that α was in fact constant; this may partly account for the fact that the results for this industry are somewhat poorer than for most of the remaining ones. There was some evidence of a decreasing trend in α (or in $\alpha\eta$) for some other industries but, except for cotton spinning (see footnote 16) the trend appeared small enough to be neglected for the purpose of our rough test.

5. The years 1942–1946 were eliminated for all industries because of war conditions and especially because of restrictions on expansion of capacity. In addition, for one industry—permissible and other high explosives—the three years 1940, 1947, and 1948 were also excluded. In the first of these years the large increase in capacity is obviously due to factors not included in our model. The remaining two years were eliminated because the reliability of the data appeared very doubtful. In the first of these years capacity is supposed to have increased by 20.6 per cent and in the immediately following year, 1948, it is supposed to have decreased by 11.6 per cent, while the largest increase in any other year was 10 per cent (in 1940) and the largest decrease 6 per cent. It should be noted in this connection that the estimates of change in capacity used in Hickman's and our own test may be subject to considerable error since they are obtained by taking the first difference of the capacity series. While the capacity estimates may be substantially accurate, any short-term error in these estimates gets, of course, tremendously magnified in the first differences. There are several instances in which the change-in-capacity series behaves in a suspiciously erratic fashion; however, the case referred to above was so conspicuous as to suggest that the observations in question should be disregarded.

Following Hickman, we selected from the scatter diagrams with the appropriate lag, for each industry, three representative ranges of utilization of capacity. The first of these is the "low" or excess capacity range, of which we give in our table only the upper value; this value represents, of course, an estimate of the quantity

[13]This last conclusion can, in fact, be anticipated from an inspection of the results reported for electric power in Hickman's Table 7, in spite of the limitations of this table.

$1/\eta a$ of equation 7a.[14] In this range, which, as we should expect from our model, stands out rather clearly for every industry, capacity mostly decreases or increases but slightly (less than 1 per cent) except for a very few "erratic" observations. In the next range, the middle or "critical" range, capacity rises moderately, typically between 1 and 2 per cent on the average. But what primarily characterizes this range is that, for many industries, behavior is somewhat variable as is revealed by the average deviation reproduced in the last column; the "coefficient of deviation" (the ratio of the average deviation to the mean) is typically much larger in this range than in the high utilization range.[15] Presumably this is the area in which the many factors that are not included in the acceleration mechanism, and which are especially significant for individual industries or firms, have an opportunity to play the largest role. Finally there is a high utilization range in which capacity increases substantially and with hardly any exception. The average yearly growth varies substantially, of course, from industry to industry reflecting differential underlying growth trends. As one might expect, this range is absent for the last two industries of Table 1, which are declining industries.[16]

[14]There is no reason to be disturbed by the fact that the estimated critical rate is everywhere less than unity (or 100 per cent) and that it varies substantially from industry to industry. In the first place the coefficient α measures, essentially, the ratio of the "technologically optimum" to the "economically desirable" rate of utilization of capacity; and, as pointed out by Hickman in the first section of his paper and by Chenery (*op. cit.*, section 1), there is no reason why this ratio should be unity. Furthermore, as we have indicated, the coefficient η need not be unity either. The fact that the critical rate of utilization depends on η as well as on α is worth noting; it reflects the fact that in a growing industry a simple and effective way of handling the problems arising from lack of precise information on the future course of sales consists in endeavoring to provide at all times a certain margin of spare capacity over and above that required by current rates of output. For a fuller discussion of this point the reader is referred to the forthcoming study of the electric power industry referred to earlier.

[15]This result would, of course, be trivial if the regression were homoscedastic. But in the present case one might have rather expected, on a priori grounds, that the dispersion would increase roughly in proportion to the mean. In fact the dispersion tends to increase, but proportionately less than the mean; nor is this result accounted for in general by the differences in the range of the "independent" variable over which the mean and dispersion is computed.

[16]The remaining two industries classified as declining by Hickman are not included in the table. In one of them, cotton spinning, there is clearly a very marked upward trend in the optimum rate of utilization α due to the increased use of multiple shifts. Since such trends cannot be readily handled with the simple technique here employed, this industry was not

It is pretty clear from the table that, as far as this test goes, the acceleration model stands up remarkably well against the "facts" collected by Hickman. Needless to say, even our test is still a rather crude and rudimentary one. A more refined test would require the use of methods of correlation analysis and should involve numerical estimates of the parameters of equation 7. These parameters are of considerable theoretical interest and, furthermore, their reasonableness could and should be checked against technological and other information relating to each industry. Also, in carrying out such a test, the very general formulation of equations 4 and 4a should be refined and adjusted to fit the specific technological and economic conditions characterizing each industry. Finally the test should endeavor to include factors other than the simple acceleration mechanism (such as the cost of securing investment funds, price-cost relations, more direct measures of expected demand, etc.) and try to assess quantitatively the extent to which these other factors can improve the explanation of behavior provided by the simple acceleration mechanism. This is precisely the type of analysis that has been carried out in the study of the electric utility industry to which reference was made earlier. The application of this painstaking and time-consuming type of analysis to Hickman's data is clearly beyond the scope of this brief comment. However, some preliminary efforts in this direction, on which I hope to report elsewhere, do suggest that the results of such analysis will be far more illuminating and useful than those obtained from the "wholesale" type of approach underlying Hickman's paper and this comment.

Pending these desirable refinements I feel that the results presented in Hickman's Table 7 and in my own Table 1 are quite adequate to substantiate the claim made at the beginning of this comment, to wit, that the acceleration principle, in the formulation underlying the recent work of Hicks and others, represents indeed a fruitful hypothesis in explaining the behavior of investment in fixed capital.

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I hope that when capital coefficient studies for all industries are brought together and published in final form an effort will be made

analyzed. In the remaining one, wheat flour, the rate of utilization of capacity (and capacity itself) remained extremely stable up to 1941 (a minimum of 50 per cent and a maximum of less than 60 per cent), while in the postwar period the last three of the five observations are not comparable with the rest of the series because of a change in the definition of capacity (cf. Hickman's Appendix A).

to distinguish the cases that rest on ex ante estimates of plant capital inputs, costs, and capacities from those that rest on ex post analysis of construction and operating records. The former, based for example on Korean War and some World War II applications for accelerated amortization or federal loans, are before-the-fact estimates made by the applicant firms; the latter are based on such data as the voluminous Defense Plant Corporation (Plancor) files. Except where applications resulted in actual plant construction and operation *and* the input-output analysts examined the ex post records, errors will be present for several reasons, among them misleading estimates and honest errors by the applicant, and incomplete or too gross presentations. I raise this point not to suggest that ex ante data should not have been used—I was party to deciding that there was no other recourse—but rather to point up a possibly serious deficiency that I hope will eventually be corrected.

These capital coefficient studies did not make this distinction clear, but except for this they have been sufficiently self-critical. I see no need to catalogue their virtues and defects or to describe their use in the Leontief input-output model. Instead I shall try to suggest that this type of information, while compiled as part of a larger input-output effort, forms a valuable body of data for use in *non*-input-output economic analysis. The simplest way to suggest this is to identify major areas of economic analysis in which the capital information can be significantly productive.

Capital Accumulation and Productivity

Economists' interest in capital accumulation and capital productivity and their relationships to economic stability and economic growth is long-standing and durable. We observe it in Marxist, Keynesian, and other underconsumption literature in connection with cyclical and long-term analysis; in the contributions of Aftalion, Clark, and Samuelson, among others, on the accelerator relation and its effect on business cycles; in recent contributions by Harrod, Domar, Schelling, Alexander, Colm, Fellner, et al, as well as by the past Council of Economic Advisers, to the question of what is a maintainable rate of capital accumulation. As Domar said of the annual gross capital formation of $36 billion, "many an economist has wondered how much longer the economy will be able to absorb capital at this rapid rate, and what will happen when a drastic fall in capital formation takes place."[1]

[1]Evsey D. Domar, "The Problem of Capital Accumulation," *American Economic Review*, December 1948, p. 777.

Consider, as an example, the Domar formulation, that (as a very simplified proposition) "$a \times s$ is the required rate of growth of income which is needed to prevent an excessive accumulation of capital,"[3] where a is the (long-run) propensity to save and s is the ratio of output (measured in terms of value added) to capital; Domar estimates a level of a, the propensity to save, but (as of 1948) can only look forward hopefully to data for s, the ratio of output to capital. Such data, requiring a certain amount of work, it is true, to transform them to the Domar s are now at hand in the capital coefficient studies of the interindustry program. For example, cursory examination of the industrial capital coefficients I have at hand indicates a ratio of annual capacity to capital in the general neighborhood of 2; this, of course, overlooks nonindustrial investment. Multiply by 0.4 or 0.5 (rough ratios of manufacturing value added to manufacturing value of output for the industrial classification of these capital coefficients) and get about 1 as a very crude approximation of Domar's definition of s. Multiplying this value of s with his estimate of a of 10 to 12 per cent, we have $a \times s$ equal to 10 to 12 per cent, the required annual rate of growth of income needed to prevent an excessive accumulation of capital, assuming all savings are allocated to income generating investment. This is a very high rate and would be high relative to present annual income growth conceptions of 2.5 and 3 per cent for the United States, even if the estimate were wrong by a factor of 2. Surely it would be worthwhile to exploit input-output capital coefficients carefully in connection with the appraisals of economic growth rates of the United States and foreign countries, including the USSR, on which the National Bureau of Economic Research has recently launched a new large project. In such exploitation I suggest that it is essential to exploit the detailed nature of these interindustry capital studies. For example it is necessary to improve the definition of Domar's s in several ways, among them by taking account of the extent to which s varies depending on the industry in which the capital is invested. I think it is unnecessary for me to show how these data are directly useful for accelerator relation analysis other than to point out that, because of the capital coefficients now available, the accelerator can be a vector instead of a single number.

Industrial Location and Regional Economic Growth

From such capital and capacity studies we obtain insight into at least one reason for the strong tendency for industries to grow

[3] *Ibid.*, p. 781.

where they are. The basic data demonstrate that it is almost always possible for an existing plant to create an increment of additional capacity at a cost less than that of a new plant built at an entirely separate location. In part this is because the plant was intentionally (with an eye on future expansion) or unavoidably (on account of indivisibilities or errors) constructed with excess actual or potential capacities in certain departments. And in part this is is because, even though a plant is constructed with exactly equal capacities in each department, differential technological advances in the various departments work to create disparities as time passes. In either case, and in others producing the same result, we learn from capital studies such as these that a large fraction of growth in capacity takes place by "unbalanced" expansion of existing plants on or near their present sites.

The capital studies at hand fall far short of settling these industrial-location and regional-growth questions, of course, but they suggest new research, and they offer for such research more than just bare hypotheses but rather a substantial body of pertinent, organized data.

Further Study of Capital

The detailed character of the capital-coefficients work indicates approximately the particular forms of the investment goods. This opens paths for a variety of further capital studies: study of the convertibility of capital, including linear-programing exploitation of the data; examination of economists' concepts of maintenance, depreciation, and obsolescence in terms of the particular capital goods subject to them; illumination of (if it is susceptible to illumination) the distinction between capital widening and capital deepening, which has interested some theorists; measurement of capital economies of scale; and inquiry into the time path and total time involved in the investment process of expanding capacity at existing and new sites. I find this last area particularly promising because I believe it will be found that many industries can expand capacity as fast as demand growth, cushioned by inventories, calls for increased output. To the extent that this is true, in many cases firms have the opportunity of meeting increase in demand at unchanged or lower cost by increasing capacity instead of operating on the rising portion of a static cost curve.

Other Applications

The availability of these capital data makes a number of other areas of economic analysis subject to improved research. One is appraisal of the particular existing producers' goods on which research, invention, and innovation can be expected to impinge. Another is analysis of certain market structures and organizations; similarities of capital and technology among different industries, ascertained from these capital data, sometimes characterize prospects for both possible future competition and possible future combination. For these cases it thus becomes possible to analyze the problem of entry in terms of specific capital requirements and technical know-how. Another is interregional comparisons of technologies as embodied in capital accounts. Yet another is economic development analysis, which has always been hungry for information on which capital inputs at what costs are needed to increase capacity. Finally, analysis in the areas of civil defense, the consequences of hypothetical air attack, and recuperation obviously need these capital data.

REPLY BY MR. GROSSE, The Rand Corporation

Harold J. Barnett very properly raises the question of whether the data on capital expenditures and capacity increases derived from applications for accelerated amortization are reliable, and points out that some of these are before-the-fact estimates. His suggestion that ex ante and ex post data be identified in future publications is a good one. In the meantime I want to add a few general notes on this problem.

For almost all plants, the data on capacity expansion were engineers' estimates. The few exceptions are those where capacity information was implied by wartime production records. In an effort to check the accuracy of the engineers' estimates of capacity, the Bureau of the Census studied production records for 1941–1943 for a sample of sixty-eight plant expansions used in Harvard University's analysis of the chemical industries. This study indicated about three-fourths of the expansions in production were within 11 per cent of the estimates made by the engineers, as shown in the table below.

With regard to the cost information, the data from World War II records are, with trivial exceptions, actual expenditures. Data from current applications, on the other hand, are for the most part ex ante estimates. The relative importance of the two sources is not uniform in the industry studies. In some, as for copper mining, records from both time periods were used, while in others the coefficients were based on World War II information only, as for chemi-

Production Increases in Relationship to Projected Changes in Rated Capacity in Chemical-Producing Plants

	Number of Cases		
Per Cent Difference	*Greater*	*Less*	*Total*
0			20
1–5.9	10	11	21
6–10.9	7	1	8
11–15.9	4		4
16–20.9	2	3	5
21–25.9	2	2	4
26–30.9	1		1
31–35.9		2	2
36–40.9			
41–45.9			
46–50.9			
51 or higher	3		3
Total	29	19	68

Source: Production data from Census Form CMR-102A. Capacity data from certificate of necessity.

cals, or current information only, as in cement. In using the industry reports as they now stand, a check on the time period from which the data were drawn can serve as a guide to whether the cost data are ex ante or ex post.