Evaluating Recent Trends in Capital Formation

Since 1984 real gross nonresidential fixed investment by nonfarm business has grown at a 7 percent pace, considerably faster than in earlier periods Its share of real nonfarm business output has averaged over 14 percent in the 1980s, well above its norm for the last generation (Table 1, columns 1 and 2) Some analysts have argued that this strong investment performance reflects an improved business climate and is likely to provide long-term gains in productivity and competitiveness.[1]

A more sobering conclusion emerges from an analysis of capital stock and depreciation data provided by the Department of Commerce[2] The pickup in investment is highly correlated with an increase in the estimated depreciation of the capital stock. Subtracting investment that merely replaces aging capital leaves a more modest level of net investment and capital formation (Table 1, columns 3 and 4). This rate of net capital formation is below the average of the postwar period. The key factor in this rising depreciation rate is the shifting of investment to shorter lived capital goods. A shift towards capital that has to pay for itself over a shorter lifetime may raise the measured short-term contribution of capital to output but lower the contribution over the longer term.

[1]See, for example, John A Tatom, "U S Investment in the 1980s The Real Story," Federal Reserve Bank of St Louis *Review*, vol 71, no 2 (March-April 1989), pp 3-15

[2]The most recent data are presented in John C Musgrave, "Fixed Reproducible Tangible Wealth in the United States, 1985-88," *Survey of Current Business*, vol 69, no 8 (August 1989) Historical data are published in Department of Commerce, Bureau of Economic Analysis, *Fixed Reproducible Tangible Wealth in the United States, 1925-85* (Washington, D C Government Printing Office, June 1987)

Commerce Department measures of net and gross capital stock growth tell similar stories These two capital stock measures are alike in reflecting the scrappage of older capital equipment but differ in the time pattern they use to depreciate older capital The *gross* capital stock represents the cost of replacing all installed capital equipment currently in use Capital goods are subtracted from the gross capital stock only at the end of their estimated service lives The *net* capital stock, by contrast, subtracts estimated depreciation from the capital stock on an ongoing basis Despite these differences, the two capital stock measures provide a qualitatively similar picture of the slowdown in capital accumulation Both the gross and net capital stock are growing at a weaker pace than in the 1960s and 1970s (Table 1, columns 5 and 6). Moreover, the growth in capital per worker is quite low (Table 1, columns 7 and 8). These data do not support the view that rapid capital accumulation is supporting output or labor productivity growth more strongly now than earlier in the postwar period

At first glance, the slowdown in the growth of the gross capital stock seems at odds with the acceleration of gross investment However, capital that has been scrapped at the end of its service life is subtracted from gross investment to calculate the change in the gross capital stock The shift to shorter lived capital in recent years has increased the rate of scrappage and reduced the rate of growth of the gross capital stock

The relationship between net investment and the growth of the net capital stock is closer than that for the two gross series Essentially, net investment equals the change in the net capital stock. Net investment has fallen off as a share of output in the 1980s, and net capital stock growth has also weakened

In some respects the contrasts between measures of gross investment and capital stock growth are even more striking for the manufacturing sector than for all nonfarm business (Table 2) After falling sharply in the early 1980s, gross investment has been growing at a robust pace since the mid-1980s The two capital stock measures, however, show an anemic performance, with growth rates well below those of earlier periods In part, the weak manufacturing data reflect the relative weakness of the manufacturing sector in this expansion. However, the strong growth in gross investment since the mid-1980s, even when combined with the loss of manufacturing jobs, does not begin to restore per capita capital formation to 1960s levels (Table 2, columns 7 and 8) The stagnation of employment in the sector is not being offset by an accelerated rate of capital growth

The conflicting messages conveyed by different measures raise the question Which set of data offers the most reliable view of the country's economic performance? If one accepts the gross investment data as indicative of the confidence in, and future prospects for, economic growth, then an optimistic view is justified. If one focuses instead on capital stock growth, then a more conservative evaluation of prospects is in order Clearly, the answer is important for analyzing the long-term performance of the American economy If the optimistic view is correct, then the economy may be able to grow out of the external and federal government deficits without a reduction in living standards or a loss of government services If the pessimistic view is correct, then the nation should, at the least, look for policies to stimulate capital formation [3]

Although economic theory suggests focusing on capital input as an indicator of capital's contribution to output, using capital stock data as a measure of the flow

[3]See, for example, M A Akhtar, "Adjustment of U S External Balances," Federal Reserve Bank of New York *1988 Annual Report*

Table 1

Indicators of Capital Formation in the Nonfarm Business Sector

	1 Growth in Gross Investment	2 Gross Investment as Share of Output	3 Depreciation as Share of Output	4 Net Investment as Share of Output	5 Growth in Gross Capital Stock	6 Growth in Net Capital Stock	7 Growth in Gross Capital per Worker	8 Growth in Net Capital per Worker
1984-88	7 04	14 85	11 41	3 44	3 53	3 20	0 26	−0 06
1979-88	3 90	14 64	11 18	3 46	3 56	3 17	1 45	1 06
1973-79	5 31	13 36	9 60	3 76	3 79	3 53	0 92	0 66
1961-73	5 59	12 69	8 40	4 29	3 74	4 26	1 60	2 11
1948-61	3 01	11 93	8 23	3 69	2 70	3 74	1 70	2 72

Note Investment, depreciation, capital stock, and output data all refer to the nonfarm business sector and are measured in constant 1982 dollars
Sources Department of Commerce, Bureau of Economic Analysis, for investment and capital stock data, Bureau of Labor Statistics for data on labor input

Table 2

Indicators of Capital Formation in Manufacturing

	1 Growth in Gross Investment	2 Gross Investment as Share of Output	3 Depreciation as Share of Output	4 Net Investment as Share of Output	5 Growth in Gross Capital Stock	6 Growth in Net Capital Stock	7 Growth in Gross Capital per Worker	8 Growth in Net Capital per Worker
1984-88	5 90	9 51	8 91	0 60	1 80	0 85	0 80	−0 14
1979-88	0 92	10 52	9 10	1 42	2 47	1 63	3 05	2 20
1973-79	6 30	11 44	8 31	3 14	3 87	3 44	2 54	2 12
1961-73	5 09	11 11	7 49	3 62	3 98	4 31	2 61	2 91
1948-61	1 09	10 53	7 65	2 88	3 37	3 43	3 16	3 20

Note Investment, depreciation, capital stock, and output data all refer to the manufacturing sector and are measured in constant 1982 dollars
Sources Department of Commerce, Bureau of Economic Analysis, for investment and capital stock data, Bureau of Labor Statistics for data on labor input

of capital services poses several problems These difficulties have led some economists to recommend gross investment as an indicator that is theoretically imperfect but superior in practice to the commonly used measures of the capital stock.[4] For this reason, this article considers a broad set of capital input indicators from both a theoretical and practical viewpoint

Mindful of the apparent contradictions in the data, we begin by discussing the theoretical role of capital in economic growth, the conceptual basis for measuring the input of capital, and the strengths and weaknesses of the various approximation techniques used to measure the aggregate capital input The potential pitfalls of some widely used measures are illustrated in a simple example. Next, we present alternative capital input data and discuss their implications for economic growth. Finally, we compare the ability of a number of capital input measures to explain economic growth over the last thirty years, arguing that if a measure correctly reflects the contribution of capital to output growth, its movements ought to be reflected in the movement of output.

Our analysis suggests that while no single capital input measure dominates all others, the various capital stock measures more accurately characterize recent and prospective economic performance than does gross investment. The higher gross investment rate has not raised capital input per head at a pace comparable to that in the 1960s. Any positive contribution to growth made by the shortening of the average life span of capital will wear off quickly as the composition of the capital stock is stabilized. Any improvement in trend labor productivity growth (especially in manufacturing) in the 1980s is more likely due to enhanced technology, greater competition, and a better skilled labor force than to more rapid capital accumulation

The data show that the contribution of capital to overall economic growth is about the same as, or slightly lower than, it was throughout the postwar period. In manufacturing, however, the contribution is markedly lower. There is little to indicate that the current pace of capital formation will propel the economy along a higher trend output path, unless technology is embodied in new capital to a much greater degree than the data can capture. The analysis suggests that if capital formation is to help accelerate growth, it will require added domestic savings.

These conclusions are not dependent on a particular measure of capital formation An important message of the data is the broad similarity in the movements of many capital input measures and the rough equality of all such measures in explaining economic performance Economists have spent much effort refining theoretical and empirical measures of the capital input. The resulting estimates depend heavily on strong theoretical assumptions and fragmentary disaggregated data. From a policy perspective, it is reassuring to note that straightforward, readily observed measures of the capital input — such as the net and gross capital stocks — move in line with more sophisticated measures based on disaggregated data

Measurement of the capital input[5]

The Commerce Department makes two estimates of real nonresidential capital stock The gross capital stock is the sum, valued at reproduction cost, of all installed plant and equipment. New capital and old capital of the same type are valued equally The net capital stock deducts accumulated depreciation from the gross stock estimate. New capital is weighed more heavily in the net stock estimate than is old capital of the same type, because it has accumulated less depreciation.

The gross and net capital stock estimates do not necessarily represent estimates of the capital input — the contribution of capital to production This is the product of the quantity of capital and its marginal product. As the existence of two official measures suggests, the quantity of capital is difficult to measure because of the heterogeneity of the capital stock and the difficulty of summing capital of the same type but of different ages ("vintages").

The marginal product of a capital good cannot be measured directly, just as the marginal product of labor is often difficult to identify. The measurement practices used reflect two different approximations. The first and theoretically preferable approach is to treat capital analogously to labor. Just as the marginal product of labor can be inferred from workers' wages, so can the marginal product of capital be inferred from the cost of renting capital. However, the measurement of capital's marginal product in this way is harder than the corresponding calculation for labor because rental markets for capital are thin.

In theory, rental rates and the cost of capital can be deduced from financial and tax data, but these calculations are difficult to make and their precision is always uncertain. Capital goods have lifetimes stretching over several years. The contribution to output needed to recover financing costs will depend on tax rates and

[4]See Frank de Leeuw, "Interpreting Investment-to-Output Ratios," Bureau of Economic Analysis, Discussion Paper no 39, March 1989, and Maurice FitzGerald Scott, *A New View of Economic Growth* (Oxford University Press, 1989) Scott proposes a theoretical justification for focusing on gross investment

[5]A recent technical study of this subject is E Bjørn, *Taxation, Technology, and the User Cost of Capital* (Amsterdam North-Holland, 1989)

benefits, expected capital gains, and the effect of wear and tear on the capital good's productivity over the years. A further complication is the possibility that the operating characteristics of installed capital may not be altered to reflect changed financial and tax considerations.

Because the reliability of cost of capital calculations is uncertain, a much simpler approximation is often used. The marginal product of each type of capital is assumed to be stable and the services of capital are assumed to be in proportion to the quantity of capital in use

Even with this simplification, measurement of the capital input is not entirely resolved Determining how the flow of services from capital changes over time poses additional problems A lightbulb, for example, produces roughly the same light towards the end of its life as at the beginning. Knowing the number of lightbulbs in operation is a good guide to the services provided by the lightbulbs, irrespective of their ages The change in the productive stock is simply the number of new lightbulbs installed less the number retired at the end of their service life An automobile, by contrast, is likely to require some servicing and repairs as it ages, adding expenses that would have to be subtracted from the automobile's product Because of the decline in the automobile's net marginal product over time, it is not sufficient to sum the number of automobiles operating in order to estimate their contribution to production One would have to know the age distribution as well.

The Bureau of Economic Analysis (BEA) makes both types of calculations. The use of the gross capital stock as a capital input measure formally requires the "one-hoss-shay" assumption that the productivity of a piece of capital does not diminish over its service life Capital goods are assumed to provide a constant flow of services until the end of their normal lifetime, when they are scrapped [6] The use of the net capital stock as a capital input measure requires the assumption that the straight-line depreciation calculated by BEA reflects an actual loss of productivity. Ultimately, analysts face an empirical question Which measure best approximates the time pattern of a capital good's productivity over its lifetime?

Summing either the gross or net capital stocks across types could provide exact proxies for the aggregate capital input if all types of capital had equal productivity or if the mix of the capital stock and the productivity of each capital type remained unchanged These conditions, however, rarely exist Short-lived capital has to recover costs over a shorter span than long-lived capital and hence, other things equal, has to yield a higher gross return per year Investment in short-lived capital goods has exceeded that in long-lived goods in recent years, shifting the capital mix towards shorter lived goods

As neither the equal productivity or unchanged mix assumption holds in reality, the crucial issue is the size of the error that will result from using simple capital aggregates, such as net or gross capital stocks, to approximate service flows Intuitively, the error would emerge because high-productivity capital is down-weighted relative to low-productivity capital in the simple aggregates Simple algebra, summarized in the Appendix, indicates that the weighting error is directly proportional to the difference in marginal productivities and growth rates of different capital types and inversely proportional to the relative sizes of the different capital stocks.[7] Nevertheless, one additional factor works to mitigate the biases introduced by these effects The faster growing capital type may be growing faster because its price is falling, suggesting that its marginal productivity is also falling The faster growth rates could reflect the less productive uses to which the capital is put

A simple simulation illustrates some elements of the mix problem It presents the rationale for using gross investment as a proxy for capital service flows and also proposes two other capital service measures that deal more directly with the mix shift problem. Our hypothetical economy produces output using only capital The capital is of two types short-lived capital with a five-year service life and long-lived capital with a twenty-year service life Both types emit services at a constant rate throughout their lives, that is, we are assuming a "one-hoss-shay" economy.[8] We also assume that there is no change in the marginal productivity of either capital type over time In addition, both capital types are equal in present value terms — the present value of the services emitted by one dollar of short-lived capital is equal to the present value of the services emitted by one dollar of long-lived capital. We also assume that the economy's real interest rate is fixed at 4 percent Given these assumptions, the annual service flow from a $100 investment in short-lived capital is $22 46, and from a $100 investment in long-lived capital, $7 36 [9]

[6]The actual procedure is slightly more complicated since scrappage is assumed to follow a probability distribution around a mean lifetime for each category of capital In general, though, we have little way of knowing whether BEA assumptions about the service lives of capital and the discard patterns of businesses are accurate

[7]The intuition behind the latter relationship is that if one type of capital dominates the capital stock, the growth of services will be dominated by the growth in this asset

[8]Substituting the assumption that the flow of services falls 20 percent per year from short-lived capital and 5 percent per year from long-lived capital leads to no substantive change in the analysis

[9]These service flows are calculated by assuming that the flows are received at the end of the year and that the present discounted

By assumption, gross investment is fixed at $100 Initially, 75 percent of investment is in long-lived capital In the initial steady state, the net capital stock amounts to $762.50, of which $50 is short-lived capital and $612 50 long-lived capital[10]

We then alter the composition of the gross investment flow permanently, placing $40 in the short-lived form Since short-lived capital depreciates more rapidly than long-lived capital, the switch results in an increase in depreciation and a decline in net investment and the net capital stock (Chart 1) The gross capital stock also declines, because the shift to shorter service lives increases the fraction of the capital stock that reaches the end of its service life in any year. In the long run, the net and gross capital stock stabilize, depreciation falls back to $100, and net investment is again zero

In the short run, the flow of capital services behaves quite differently from the net and gross capital stocks The increase in short-lived capital initially results in an increase in the capital input because short-lived capital emits services at a higher rate than long-lived capital Eventually, the smaller stock of capital overcomes this effect, and the flow of capital services falls to a new equilibrium rate below its initial level

Neither the gross nor the net capital stock perfectly reflects the time path of the capital input during the transition period Both fail to reflect the initial pickup in capital services from the switch to shorter lived capital, and although they give correct qualitative signals in the long run, they greatly exaggerate the actual decline in capital services. This problem with the aggregate capital stock data has led some analysts to advocate gross investment as a measure of the capital input They reason that while gross investment does not accurately reflect the time path of the capital input, at least it does not make any egregious errors[11]

Nevertheless, confidence in this measure appears misplaced Our example was contrived to put gross investment in its best light as an indicator The investment mix went instantly from one steady state to another In the real world, where investment growth can vary markedly from one period to the next, it is implausible that the flow of actual capital services would be well represented by investment

Furthermore, better measures of the aggregate capital input than gross investment can be readily constructed Depreciation is one such measure, it correctly increases when the investment mix shifts to shorter term assets Although depreciation provides the same misleading long-term signal as gross investment, returning to its previous equilibrium of $100, it captures the dynamics of changing service flows much better

Another alternative is to recompute the net capital stock by assigning each type of capital a weight that is the inverse of its mean service life, rather than assigning all forms of capital equal weights as is done in a conventional calculation.[12] This reweighting reflects the

Footnote 9 continued
value of the flows equals $100 A similar simulation can be found in de Leeuw, "Interpreting Investment "

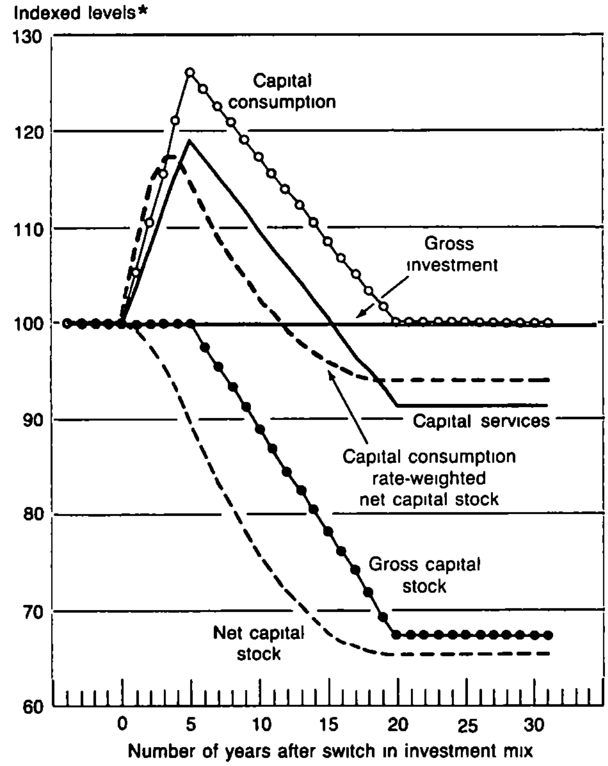
[10]This net capital stock is calculated on the basis of straight-line depreciation The results show little change if we replace the straight-line assumption by "true economic depreciation," the decline in the value of an asset as it ages

[11]See de Leeuw, "Interpreting Investment " This author also emphasizes the need to consider all physical investment (residential and nonresidential, public and private) and investment in research and education to explain economic growth

[12]A similar calculation was done for gross investment in Arnold J Katz, "An Analysis of Trends in the Intensity of U S Capital Formation and Their Determinants," *Journal of Policy Modeling*, vol 8 (Fall 1986), pp 433-70

Chart 1

Measures of Capital Services, Capital Input, and Investment



*Year of switch in investment mix = 100

assumption that short-lived capital has a higher marginal product than longer lived capital It may be viewed as a simple first approximation to a full-blown user cost calculation. In the simulation, the reweighted net capital stock provides a good proxy to the capital input it correctly increases when the investment mix shifts, and its long-run equilibrium level is below its initial equilibrium

The conclusions we draw from the simulation are that the criticisms of the net and gross capital stocks as measures of the capital input can be valid, at least for analysis of short-term movements in the capital input Gross investment may provide a marginally better index of capital services during periods of extreme shifts in the investment mix, but depreciation and the reweighted capital stock appear to provide better approximations to the actual path of the capital input Thus, if the changing composition of investment and capital is truly the key to understanding the flow of capital services, the latter two measures are preferable to gross investment

In the real world, the mix problem is likely to be less severe than in this simulation First, the actual shift in the mix has been somewhat less striking In the late 1960s the service life of the installed U S nonresidential capital stock was about twenty-one years, the recent figures still put the average service life at more than seventeen years (Table 3)[13] In the simulation the service life of installed capital falls from sixteen and one-quarter years to eleven years over a twenty-year period, about twice as fast a rate of change as actually occurred Second, to the extent that the shift to shorter lived capital in the United States was prompted by tax motives (such as the investment tax credit and the acceleration of depreciation allowances) or by relative price changes associated with improved technology (such as the price declines for computers and telecommunication equipment), it would be less likely to contribute to an acceleration of capital service flows, long-lived capital may have been replaced by short-lived capital of comparable productivity The shortened service lives would normally have led to an increase in the marginal productivity of the capital stock, but the tax advantages and relative price changes could have led to the installation of less productive short-lived capital

[13]We derived an estimate of the average service life of installed capital by dividing gross capital stock estimates by depreciation

Table 3

Service Life of Installed Capital

(Years)

	All Nonfarm Business	Manufacturing
1988	17 5	18 5
1985	18 2	18 8
1980	19 0	19 2
1975	20 2	19 9
1970	21 0	20 2
1961	22 3	20 4

Source Federal Reserve Bank of New York calculations based on Bureau of Economic Analysis data

Empirical estimates of capital formation

Lacking a universally accepted capital input measure, we consider several such measures before drawing any firm conclusions Table 4 computes the growth since 1961 of various measures of the capital input for all U S nonfarm business, and Table 5 makes the same calculations for manufacturing The alternative real capital input measures are

1) Gross capital
2) Net capital
3) Depreciation
4) Reweighted net capital
5) Bureau of Labor Statistics (BLS) index of capital services
6) Gross investment
7) Gross investment, chain-weighted

As noted above, the gross capital stock estimate does not take into account accumulated depreciation on existing capital, while the net capital stock does Recall also that gross investment is not equal to the change in the gross capital stock, because scrappage is not deducted from gross investment

Gross capital, net capital, depreciation, and gross investment are all taken from BEA data Depreciation is included because it represents the basic flow of services a piece of capital must provide it must pay for itself over its lifetime The reweighted net capital stock is computed as in the simulation Each component of the net capital stock is assigned a weight equal to the inverse of its mean service life on the assumption that the relative productivity of different pieces of capital should be roughly inversely related to their service life The BLS service flow measure is designed to capture systematically all the effects that alter the aggregate capital input These effects include shifts in the mix of capital between capital types with different productivities, and changes in the optimal productivity of installed capital resulting from changes in the cost of finance and in the structure of taxes and subsidies to capital.[14] The alternative measure of real gross investment, derived from chain-weighted price changes, may be preferable to conventionally measured real gross investment because it reflects the lowered marginal productivity of capital goods, notably computers, whose relative prices have dropped sharply over time[15] Also, changes in implicit price deflators — and hence, growth of real spending — can be distorted by shifts in the composition of real spending Price indexes derived from changes in chain-weighted deflators avoid this problem

The standard measures for the nonfarm business capital input — gross capital, net capital, and capital services — suggest that growth has been slower in this expansion than over the 1961-73 period (Table 4, columns 1, 2, and 5) Somewhat surprisingly, growth rates of all three measures throughout the 1980s have been below those of the 1970s

The measures linking capital services most closely to service lives, the reweighted net capital stock and constant dollar depreciation, tell a moderately different story They suggest neither a major improvement nor a deterioration in growth during the 1980s relative to the 1970s, but find some acceleration with respect to the 1960s (Table 4, columns 3 and 4)

Of the seven measures of capital input growth, only conventionally measured gross investment shows a definite break with past trends, beginning in the mid-1980s (Table 4, column 6) (Chain-weighted gross investment also shows a sharp improvement in the mid-1980s, but its current growth rate is comparable to that in the 1960s and 1970s) The two gross investment measures differ from all the other measures of capital services in being completely independent of capital scrappage or depreciation

[14]See U S Bureau of Labor Statistics, "Trends in Multifactor Productivity, 1948-81," Bulletin 2178, Washington, D C , 1983, for detail on the construction of this series

[15]de Leeuw, "Interpreting Investment," argues strongly for these chain-weighted measures

Table 4

Measures of Capital Input Growth: All Nonfarm Business

(Percent Change at an Annual Rate)

	1 Constant Dollar Gross Capital Stock	2 Constant Dollar Net Capital Stock	3 Reweighted Net Capital Stock	4 Constant Dollar Depreciation	5 Private Nonfarm Business Capital Services	6 Constant Dollar Gross Investment	7 Chain-Weighted Investment
1984-88†	3 53	3 20	4 93	4 84	3 64	7 04	6 03
1979-88†	3 56	3 17	4 47	4 76	3 80	3 90	3 57
1973-79	3 79	3 53	4 90	4 78	3 95	5 31	5 77
1961-73	3 74	4 26	4 20	4 32	4 09	5 59	6 09

Sources Bureau of Economic Analysis, columns 1, 2, 4, and 6, Bureau of Labor Statistics, column 5, Federal Reserve Bank of New York calculations based on Bureau of Economic Analysis data, columns 3 and 7

†1987 for capital services

Table 5

Measures of Capital Input Growth: Manufacturing Industries Only

(Percent Change at an Annual Rate)

	1 Constant Dollar Gross Capital Stock	2 Constant Dollar Net Capital Stock	3 Reweighted Net Capital Stock	4 Constant Dollar Depreciation	5 Manufacturing Capital Services	6 Constant Dollar Gross Investment	7 Chain-Weighted Investment
1984-88†	1 80	0 85	1 48	2 43	1 38	5 90	5 49
1979-88†	2 47	1 63	2 24	3 23	2 32	0 92	1 04
1973-79	3 87	3 44	4 51	4 10	3 92	6 30	7 09
1961-73	3 98	4 31	4 69	4 05	4 12	5 09	5 32

Sources Bureau of Economic Analysis, columns 1, 2, 4, and 6, Bureau of Labor Statistics, column 5, Federal Reserve Bank of New York calculations based on Bureau of Economic Analysis data, columns 3 and 7

†1987 for capital services

To make the argument that the gross investment measures are better indicators of capital services than the others, one might maintain either that the measures of depreciation and scrappage are greatly overstated or that the greater productivity of new investment relative to investment being depreciated or scrapped is significantly understated by the data Although these are theoretical possibilities, there is little evidence showing that service lives are overstated or understated, and little presumption in the literature that these factors are causing large distortions in the data Moreover, the argument for gross investment as an indicator is much more commonly based on other claims—namely, the robustness of gross investment to shifts in the composition of investment Nevertheless, as we have seen, indicators that are better at reflecting mix shifts do not show a major break with past trends

The movement in the manufacturing measures has been more dramatic than in all nonfarm business The 1980s as a whole have witnessed much slower growth in measures of the capital input, and the weakness has been concentrated in recent years The net manufacturing capital stock has shown virtually no growth in this expansion (Table 5, column 2) Overall, the first five measures show drops ranging from one and seven-tenths percentage points to three percentage points in the growth of capital input in the late 1980s relative to the 1970s Again, only conventional gross investment appears moderately robust, declining only four-tenths of a percentage point from its growth rate in the 1970s (Chain-weighted investment slowed by one and six-tenths percentage points but is still strong relative to its performance in the 1960s) Even for these investment measures, however, growth since 1979 has been very weak

In manufacturing, as in nonfarm business, the first five measures tell a consistent story capital formation is proceeding at historically low levels The measures differ in the exact level of growth, but they point to a qualitatively similar slowing Labor input has actually been falling through the 1980s, so that capital-to-labor ratios have been rising, presumably aiding productivity growth But it is hard to argue that the capital input data show either capital or labor making a rising contribution to sectoral growth [16] Technology and efficiency may be improving at a more rapid clip, but little evidence supports a similar finding for capital formation

Some of the minor differences between the measures of capital input growth for nonfarm business and manufacturing can be readily explained For example, growth in the gross capital stock in both the total nonfarm business and manufacturing sectors has slowed less than growth in the net capital stock, while the growth rate of depreciation has exceeded those of net and gross capital in every subperiod since 1973 This divergence reflects the shift of the capital stock to short-lived assets (most notably computers), a development which has tended to increase the depreciation rate on the overall capital stock During the transition period, a switch to short-lived capital will increase the growth of depreciation and reduce the growth of the net capital stock relative to the gross capital stock

The gross investment data differ from all other capital input measures in the impression they present, both for all nonfarm business and for manufacturing Conventionally measured gross investment has been growing at very rapid rates in this expansion The comparison is not quite as favorable for the chain-weighted series, still, this measure of investment has been growing about as rapidly as in the 1960s As noted above, the virtue of gross investment as a measure of capital input is that it is relatively robust to mix changes in investment Nevertheless, three of the first five capital input measures in Tables 4 and 5—reweighted net capital stock, constant dollar depreciation, and capital services—reflect these mix shifts directly, in a manner more consistent with economic theory They show flat or declining trends in capital service growth despite the mix shift Hence the use of a gross investment measure as an indicator of capital input cannot be justified by its robustness to shifts in investment composition

Which indicator of capital services works best?

Theoretical considerations, simulations, and descriptive statistics can only go so far. It may be helpful to consider whether, in a more practical context, the net and gross capital stocks are unreliable indexes of the aggregate U S capital input Regression analysis of U.S economic growth can give us a partial answer If the net and gross capital stocks are poor measures of the capital input, then they should yield explanations of overall U S growth that are significantly poorer than those provided by theoretically superior alternatives Conversely, if gross investment captures factors omitted in the standard capital input measures, it may be more correlated with output movements in practice

The table in the Box summarizes regressions explaining the annual growth of real nonfarm business output, using hours worked as the measure of the labor input and various alternative measures of the capital input The alternative capital input measures are the net capital stock, the gross capital stock, the BLS index of capital services, real depreciation, the reweighted

[16] We do not focus on output growth rates in manufacturing because critics have argued that they are implausibly rapid, and publication of substantially revised data is expected soon See Frank de Leeuw, "Gross National Product by Industry Comments on Recent Criticism," *Survey of Current Business*, vol 68 (July 1988), pp 132-33

Box: Testing the Capital Stocks in Production Relationships

Several different approaches to measuring capital and capital services are discussed in the text Each measure requires that some strong assumptions be made about the path of capital service flows The rental cost measure, preferred theoretically, is the most demanding in terms of parameter requirements Thus, there appears to be a substantial trade-off between simplicity and elegance We apply a simple criterion to identify the particular capital stock measure that outperforms the others in practice a capital measure performs better if its implied capital service flows are more closely related to output or productivity than those of the other capital measures

Output growth can be decomposed into components representing labor input growth, capital input growth, and a residual that is often termed total factor productivity growth The residual tends to be very procyclical and can be broken down into a relatively stable component, viewed as the productivity trend, and a strongly cyclical component Other assumptions, such as constant returns to scale, can also help identify the relationship Our approach is to estimate a variety of such production relationships and to select the capital input measure that contributes to the best explanation of growth

We assume a constant returns to scale Cobb-Douglas production function, which can be written in logarithmic terms as

$$\ln Y = a + \alpha \ln L + (1-\alpha) \ln K + \lambda t,$$

Performance of Capital Service Measures in Production Relationships

	Coefficients						Equation Residual Standard Errors					
	Net Capital	Gross Capital	Chain-Weighted Investment	Depreciation	Capital Services	Re-weighted Net Capital Stock	Net Capital	Gross Capital	Chain-Weighted Investment	Depreciation	Capital Services	Re-weighted Net Capital Stock
Equation												
1	0 37	0 53	0 00	0 32	0 33	−0 18	0 008	0 009	0 010	0 010	0 009	0 010
2	0 58	0 91	0 00	0 75	0 56	−0 17	0 98	0 76	1 09	0 82	0 99	1 04
3	0 35†	0 35†	0 35†	0 35†	0 35†	0 35†	0 98	0 88	3 13	0 89	0 99	1 45
4	0 35†	0 35†	0 35†	0 35†	0 35†	0 35†	1 05	0 97	4 05	1 00	1 08	1 54
5	0 24	0 21	−0 02	−0 02	0 12	0 03	0 009	0 010	0 010	0 010	0 010	0 010

1 $\ln(lprod) = a_0 + a_1 \ln(caphrs) + a_2\, cycl + \sum_{j=3}^{7} a_j T_i$

2 $dlprod = a_0 + a_1\, dcaphrs + a_2\, dcycl + \sum_{j=3}^{6} a_j D_i$

3 $dlprod = a_0 + 35\, caphrs + a_2\, dcycl + \sum_{j=3}^{6} a_j D_i$

4 $dlprod = a_0 + 35\, caphrs + 4\, dcycl + \sum_{j=3}^{6} a_j D_i$

5 $\ln(out) = a_0 + 65 \ln(hrs) + a_1 \ln cap + a_2\, cycl + \sum_{j=3}^{7} a_j T_i$

where
- lprod = nonfarm business sector labor productivity
- dlprod = the percent change in labor productivity
- caphrs = the ratio of capital input to hours worked
- dcaphrs = the percent change in the capital input-to-labor ratio
- cycl = a measure of capacity utilization (the ratio of actual to potential real GNP, as calculated by the Federal Reserve Board staff)
- dcycl = the change in capacity utilization
- T_i = a set of time trends (allowing for breaks in 1952-61, 1962-68, 1969-73, 1974-79, 1980-88)
- D_i = a set of (0,1) dummy variables (allowing for breaks in 1952-61, 1962-68, 1969-73, 1974-79, 1980-88)
- out = output in the nonfarm business sector
- hrs = manhours worked in the nonfarm business sector
- cap = the capital input

†Imposed

Box: Testing the Capital Stocks in Production Relationships *(continued)*

where Y, L, K, and λ are respectively output, labor input, capital input, and the rate of total factor productivity growth, and α and $(1-\alpha)$ are elasticities of output with respect to labor and capital (The last two parameters can be shown under constant returns to scale to equal their income shares)

This expression can be rewritten as

$$\text{(A)} \quad \ln(Y/L) = a + (1-\alpha)\ln(K/L) + \lambda t,$$

or in first difference form,

$$\text{(B)} \quad \Delta(Y/L) = (1-\alpha)\,\Delta\ln(K/L) + \lambda$$

The estimated equations differ in the extent to which the coefficients are freely estimated and whether the relationship is estimated in levels or first differences In the accompanying table, equations 1 and 2 assume constant returns to scale, freely estimate the cyclical correction, and estimate implicitly the elasticity of output with respect to the capital input In theory this elasticity should equal capital's share of output, which is about 0 35 Equation 1 is estimated in levels, equation 2 in first differences

Equation 3 imposes this theoretical response of output to the capital input, while equation 4 also imposes a cyclical response of productivity to capacity utilization of 0 4 (Both of these equations are estimated in first differences) The residual standard errors in 3 and 4 as compared with 2 indicate how much explanatory power is lost by imposing the theoretical output response elasticities on the alternative capital input measures Equation 5, estimated in levels, drops constant returns to scale, assumes that the output elasticity with respect to labor is 0 65, and estimates the elasticity with respect to capital

Looking at the regression results, we see that in equation 1 — the specification that uses the log of labor productivity as the dependent variable — the net capital stock has the closest fit, followed by the gross capital stock and the capital services index We expected that the coefficient on the capital input would be in the neighborhood of 0 35 (capital's share of output), this prediction roughly holds for four of the measures In equation 2 — the equation 1 specification in first difference form — only the net capital stock and capital services have coefficients anywhere near 0 35, but the gross capital stock and depreciation have the greatest explanatory power

In equation 3 we constrain capital's marginal contribution to output to be constant at 0 35 In this formulation, gross capital and depreciation have the closest fit. The same is true in equation 4, which imposes the additional constraint on the capacity utilization response

Finally, equation 5 constrains labor's marginal contribution to output to be 0 65 The net capital stock has the best fit, and its coefficient is closest to the hypothesized 0 35 The gross capital stock and capital services follow, while investment, depreciation, and the reweighted capital stock perform poorly

net capital stock, and chain-weighted real gross investment.

The list of capital input proxies allows for testing a wide range of assumptions about the correct way to aggregate the inputs of capital If either gross or net capital provides the best explanation for economic growth, then the problems of the changing mix of capital have not been severe (or at least have not been better addressed by the alternatives) The comparison of gross and net capital amounts to testing whether the U S capital stock has a service flow pattern more like that of lightbulbs or automobiles In other words, does depreciation occur at the end of an item's service life or continually as the item ages?

Depreciation and the reweighted net capital stock are alternative measures intended to capture any effects of the changing service life of the aggregate capital stock (The comparison of the two measures is analogous to the comparison of gross and net capital) If the BLS capital services measure provides the best fit, then there have been substantive changes in the aggregate productivity of the capital stock which must be accounted for in a rigorous fashion Finally, if the gross investment measure proves superior, it would imply that measurement problems are so severe that the best compromise between theory and reality is to assume that contemporaneous capital demand should be related to the capital input

Because regressions relating aggregate output to aggregate inputs lack a solid theoretical foundation and often give aberrant results (such as negative contributions to output from capital), we used five different specifications In the first, we assumed that the logarithm of the ratio of output to hours (that is, the log of labor productivity) was related to the logarithm of the ratio of the capital input to hours, time trends, and the cyclical state of the economy In the second, we assumed that this relationship held for the changes in the logarithms of labor productivity (that is, the relationship held for growth rates) The third specification related the growth of labor productivity less 0.35 times the growth in the capital-to-labor ratio to a cyclical variable and dummy variables for subperiods, the justification for this specification was that capital's share of output is roughly constant at 0 35, and this relationship simply imposes that constraint The fourth specification was the same as the third but limited the coefficient of the cyclical variable to 0 4 The fifth specification related the log of output less 0.65 times the log of hours to the log of the capital input. (The motivation for the tests is presented in the Box)

On the whole, the results suggest that no one measure is clearly superior to the others, but some patterns emerge First, out of the five production relationships estimated, the gross capital stock performed best in three and the net capital stock in two Depreciation and capital services followed The reweighted capital stock performed poorly, and the indicator based on gross investment showed the least explanatory power Knowledge of gross investment levels or growth rates, without any knowledge of the capital stock, provided virtually no useful information about output.[17]

While the gross capital stock showed greater explanatory power in three of five regressions, the estimated coefficients for the net capital stock were closer to the expected 0 35 value In both specifications in which this elasticity was imposed, however, the gross capital stock produced the equation with the least residual error in output growth.

The theoretically preferred measure of capital services that was based on estimated capital rental rates performed somewhat worse than net and gross capital, but generally its performance was not far below that of net and gross capital. In coefficient size and residual error, it was a little closer to the net capital than to the gross capital stock

While different capital input measures "fit" best in different specifications, in no case did gross *investment* outperform these other measures[18] To the extent that methods based on production functions are valid, there was no evidence that gross investment flows provided an adequate approximation to the flow of capital services.

Such exercises are suggestive but hardly conclusive. The validity of the test is highly dependent on a correctly specified production relationship. Substantial quality shifts in labor input, the absence of constant returns to scale, the existence of a more complicated production relationship than is assumed in our regression equation (for example, translog as opposed to Cobb-Douglas), or the unstable evolution of total factor productivity could undermine the usefulness of the test. Despite these concerns, the test does determine how well the various capital measures fit into a commonly used production framework Moreover, it provides some guidance in determining which capital input measure provides the most information about trend output growth and whether or not the mix shift has had a discernible effect on productivity and output growth.

Nevertheless, it is fairly astonishing to find that gross and net capital do so well in the regressions relative to measures designed to reflect the changing mix of the capital stock. Although the change in the mix has been less rapid than in the simulation, short-lived capital has

[17]Conventionally measured, as opposed to chain-weighted, gross investment also performed poorly when tested in similar regressions

[18]Beginning the regressions in 1973 did not alter the relative performance of investment and the alternative capital input variables

Table 6

Growth of Gross Capital Stock Types: All Nonfarm Business

(Percent per Year)

	Short-Lived Capital (Service Life of Eleven Years or Less)		Medium-Lived Capital (Service Life of Twelve to Twenty-Four Years)		Long-Lived Capital (Service Life of Twenty-Five Years or More)	
	Change in Real Stock	Price Change	Change in Real Stock	Price Change	Change in Real Stock	Price Change
1984-88	8 47	−5 27	2 90	3 54	2 27	3 05
1979-88	6 74	0 02	3 88	5 54	2 40	5 41
1973-79	7 19	7 56	4 32	8 95	2 75	9 05
1961-73	5 74	1 85	4 00	3 48	3 26	3 69

Source Federal Reserve Bank of New York calculations based on Bureau of Economic Analysis data

Note Price changes based on implicit deflators grown substantially as a share of the total capital stock over the last generation, and the difference in growth rates has increased (Table 6) Why is it so hard to detect the influence of the changing mix?

The most plausible answer is that the shift of the capital stock did not necessarily imply a shift to assets with greater immediate productivity One reason, mentioned above, is the possible role of taxes in spurring the shift, a change in asset mixes due solely to tax considerations does not necessarily imply that either mix is more productive (as opposed to profitable)

More important perhaps, the shift in the relative prices of capital goods has also had implications for relative productivities Primarily because of the sharp decline in the price of computers, the cost of short-lived capital has plunged, both in absolute terms and relative to long-lived capital (Table 6) The effect of prices on user costs is very similar to the effect of tax incentives low-priced capital goods are purchased to the point that the last, or marginal, unit is placed in a low-productivity setting. Thus, changes in the relative price of capital goods affect the marginal productivity of capital types

The sharp drop in the relative price of short-lived capital goods makes it plausible to argue that the recent switch to short-lived capital has not markedly changed the overall productivity of the existing capital stock Thus, the net and gross capital stocks can be plausible approximations to the capital input (The Appendix presents a more technical discussion of the approximation error involved in using simple sum aggregates of the capital stock)

Conclusion

A wide variety of capital input measures for the nonfarm economy — including the Commerce Department's estimates of the gross and net capital stocks and alternative measures designed to capture the output effects of a changing capital mix — suggest that in recent years there has been a continuation of 1970s growth rates at best, or an outright decline in growth. In sharp contrast, the growth of gross investment has accelerated during this expansion It has been argued that in periods of rapid shifts in the capital mix, gross investment may give some clues to the growth of the capital input — better clues, at least, than those provided by the gross and net capital stock measures. Thus, a conflict emerges if we follow the capital stock data, we would conclude that growth in the capital input has not improved in recent years, if we follow the gross investment data, we would conclude that the capital input may be growing more rapidly than in the past.

The recent divergence in growth between the capital stock measures and other indicators designed to capture the effects of a changing mix has not been as marked as the divergence between the capital stock measures and gross investment In empirical relationships linking nonfarm business inputs to output, the simple net and gross capital stock measures did as well as, or better than, the alternative capital input measures, and gross investment did worse than any of the other measures.

The evidence for the entire nonfarm business sector suggests that the growth in the aggregate capital input has not accelerated in this expansion Applying these results to manufacturing gives a stronger verdict the growth of all the alternative measures of the capital input, except for gross investment, has been decidedly weak A reversal of this trend would strengthen the growth of U S industrial capacity and aid the U S external adjustment process by augmenting the potential output available to meet the growth of foreign and domestic demand.[19]

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[19]The relationship between industrial capacity growth and the adjustment process is described in Akhtar, "Adjustment of U S External Balances", and in R Spence Hilton, "Capacity Constraints and the Prospects for External Adjustment and Economic Growth 1989-90," Federal Reserve Bank of New York *Quarterly Review*, vol 13, no 4/vol 14, no 1 (Winter-Spring 1989), pp 52-68

Appendix: Approximating the Error from Simple Sum Aggregates of the Capital Stock

Assume that three types of capital are in service Type 1 capital is short-lived, type 2 has a medium life, and type 3 is long-lived They emit services at the rates μ_1, μ_2, and μ_3, respectively The total input of capital services, KS, is then

(1) $KS = \mu_1 K_1 + \mu_2 K_2 + \mu_3 K_3$

Suppose we want to approximate the growth of KS by the growth of the simple sum of the physical capital stocks, $KG = K_1 + K_2 + K_3$ The approximation error, AE, will be determined by

(2) $$AE = (K_1K_2(\mu_1 - \mu_2)(\dot{K}_1 - \dot{K}_2) + K_1K_3(\mu_1 - \mu_3)(\dot{K}_1 - \dot{K}_3) + K_2K_3(\mu_2 - \mu_3)(\dot{K}_2 - \dot{K}_3) + \dot{\mu}_1K_1 + \dot{\mu}_2K_2 + \dot{\mu}_3K_3)/(KG^*KS),$$

where the dot over the variable indicates a growth rate

Note that if the rate of service emission is unchanged over time, and either the emission rates are equal across types or the growth rates of the capital types are equal, there will be no error.

In reality, we observe the growth rates of capital stocks, not the services they emit But with some simplifying assumptions we can estimate the approximation errors that result from treating the growth of the U S gross capital stock as the growth of the capital input

To simplify, we divide the capital stock into short-lived (service life, zero to eleven years), medium-lived (twelve to twenty-four years) and long-lived (twenty-five or more years) goods The average service life is calculated for each of these goods In general this composite average service life will vary from year to year as the mix of capital types within each category changes For simplicity we ignore tax effects and assume that the real interest rate is constant at 4 percent The "one-hoss-shay" assumption is made, so each capital good is assumed capable of producing the same physical product from installation to the end of its service life

Apart from differing service lives, the major factor affecting the relative productivity of the different types of capital is their cost and the rate of change in relative prices Consider an investor buying a computer at time t versus time t+1 Because the real price of the same computer will fall between t and t+1, the computer's contribution to output has to be high enough in period t to offset the gain that would be realized by the investor who waited another period before purchasing a cheaper computer Each period, however, the same machine gets cheaper and cheaper, implying that the value of its marginal product is falling For example, if the real price of computers falls by 50 percent over five years, a computer bought today has to be only half as productive on the margin as an identical computer purchased five years earlier That is, computers will be used less and less productively

This last consideration is very important If investors are purchasing many short-lived capital goods because they have become relatively cheap, the diminished value of their marginal product may substantially offset the effect of shorter service lives on the growth of capital services

The exact formula used to estimate the value of the marginal products of capital types with varying service lives is

$$\mu_j = P_j(1 - V_j)/(V_j^{(SL_j+1)}),$$

where

- μ_j = the value of the marginal product of the j'th capital type
- P_j = the price of the j'th capital type relative to overall capital goods prices,
- V_j = $(P^t_j/P^{t-5}_j)/1\ 04$, the rate of relative price appreciation (averaged over five years) divided by the assumed real interest rate, and
- SL_j = the average service life of the j'th capital type

The time superscript is suppressed in all cases except in the calculation of V_j †

The table shows the approximation errors that arise when the gross capital stock is used to calculate the capital input We see that in the 1960s the gross capital stock grew at virtually the same rate as the hypothetical capital input In the 1970s the capital input grew more rapidly, but in the current expansion the gross capital stock has grown more rapidly than the approximate capital input

Average Approximation Error
(Growth of Hypothetical Capital Input Less Growth of Gross Capital Stock, Percent per Year)

1984-88	−0 33
1979-88	−0 11
1973-79	0 57
1961-73	0 17

In general these approximation errors are small, less than 15 percent of the average capital stock growth rate Moreover, when converted to a contribution to labor productivity or overall growth (multiplying by an average capital share of 0 35), the error is extremely small and unlikely to be significant in any policy debate

†The price changes are calculated over five-year periods to smooth out short-term price fluctuations, which probably do not greatly affect decision makers