Productivity Growth and Investment in Equipment: A Very Long Run Look

J. Bradford De Long
Harvard University and NBER

September 1991

Over the past century the long-run growth of industrial economies shows a strong association between rates of investment in machinery and equipment and long-run rates of economic growth. Each one percentage point increase in the machinery investment share of national product increases national product per capita growth by approximately 0.4 percentage points per year. A number of considerations suggest that machinery investment is in a sense *the* strategic factor in long-run productivity growth—a hypothesis also suggested by narrative accounts from the history of technology.

I. Introduction

The share of output devoted to investment in machinery and equipment, and the rate of national product per capita growth have been strongly associated over the past century in presently-industrialized countries. Each one percentage point increase in the machinery investment share of national product has carried with it an increase in the growth rate of national product per capita of 0.4 percentage points per year or more.

This paper documents this association in a data set extending back to 1870 covering six industrial nations—Canada, Germany, Italy, Japan, the United Kingdom, and the United States. The association between equipment investment and growth holds both within and between nations and periods. Several considerations suggest that the major part of this association is *causal:* it is more nearly the truth to say that high investment in machinery and equipment leads to rapid growth than to say that rapid growth leads to high profits and hence high rates of investment.

A similar association holds between machinery and equipment investment and growth in the post-World War II era. Hayn (1962) and Díaz-Alejandro (1970) argued that Argentina's extraordinarily poor economic performance in the post-World War II period was due to a very low rate of investment in machinery and equipment resulting from counterproductive economic policies. Hill (1964) found a strong bivariate association between equipment investment and economic growth over 1954–62 for a subset of OECD countries. De Long and Summers (1991) ave found a very strong association—both bivariate and partial—between equipment investment and economic growth over 1950–85 for a broad sample of around sixty nations.

The existence of such a strong association in both very long run and post-World War II data sets lends substantial support to the proposition that equipment investment is in a sense *the* strategic factor in long-run productivity growth. The link between equipment investment and productivity growth appears to be a pervasive feature of economic growth and industrialization. It may well reflect a fundamental link of growth with *mechanization,* with the construction and acquisition of machines embodying the technologies of the industrial revolution and that multiply human productive powers manyfold.

The substantive sections of this paper are organized as follows. Section II lays out some of the issues in the ongoing debate over the character of the long-run growth process, and argues that evidence on the association between equipment investment and productivity growth can help resolve this debate. Section III discusses the reliability of the underlying data. Section IV presents evidence on the association of investment in equipment and productivity growth over the very long run. Section V investigates the important issue of causality—does high equipment investment cause fast growth, or does fast growth lead to high equipment investment? Section VI sketches a conception of the economic growth process consistent with both the evidence on macro patterns reported here, and with the micro evidence reported by historians of business and technology. And ection VII draws out some implications and provides a brief summary.

II. The Issues

For more than a century, historical discussions of long-run growth have emphasized the role of mechanization—and thus of investment in machinery and equipment—in driving the enormous increases in labor productivity of the past two centuries. The people of the industrial nations of the world are today at least eight times as wealthy as their predecessors were a century ago, and perhaps twenty times as wealthy as they were two centuries ago. The citizens of the industrial world are rich today because they know how to cheaply make and have poured resources into making the machines that multiply the productive powers of human labor more than tenfold.

Economic historians by and large see the industrial revolutions of the past two centuries as a succession of technological innovations that raise productivity and living standards when their fruits are embodied in capital goods. In their narratives, factors supporting a high rate of machinery investment are given a prominent role in the diffusion of innovations. A low price of machines—the ability to make industrial capital goods cheaply—and a high quantity of savings devoted to the purchase of machinery and equipment have always featured prominently in economic historians' discussions of the sources of modern economic growth. This is the picture drawn most famously by Gerschenkron (1962). It has been further developed by Rosenberg (1963a), Landes (1969), and Pollard (1982), and many, many others. This tradition has, at least since Blanqui (1837), stressed the link between investment in machinery on the one hand and growth in the productivity of workers on the other.

In recent decades, development economists and theoretically-oriented growth economists have drifted away from the points of view adopted by economic historians. They no longer focus on the identification of economic growth with mechanization and with investment in equipment. Instead, development economists and growth economists have by and large come to believe that the importance of capital accumulation in growth had previously been overstated, and that other factors—like formal education, economies of scale, terms of trade, and so forth—were more central.[1]

---

[1]Rostow (1990) surveys the development of theories of economic growth.

Clark (1937) was among the first to argue that capital deepening was *not* responsible for the bulk of growth in output per capita.[2] Growth accounting studies in the tradition of Solow (1957) have also found that capital deepening is responsible for only a small part of advances in labor productivity.[3] The general drift of this line of argument is that a high rate of investment is neither sufficient nor necessary for economic growth: the strategic factors in long-run economic growth are education, skills, and organizations, more than tangible physical capital goods.[4]

This paper argues that economists should shift their beliefs back in the direction of the Gerschenkronian view, for the association between productivity growth and equipment investment is very strong: differences in machinery investment shares can account for half of the total variance—both within and across nations and eras—of national product per capita growth in the very long run sample analyzed in this paper.[5] The association is far stronger for *equipment* investment than for investment in structures, or for total investment. A strong case can be made that this association is causal. The components of equipment investment that are most likely to be exogenous are as strongly associated with increases in productivity as is equipment investment as a whole.

Rosenberg (1963b) is one of many who has argued on the basis of micro studies of technological innovation that the construction, acquisition, and installation of machines is a key

---

[2]From a present-day perspective, Clark's analysis confuses a reduction in macroeconomic slack with an increase in potential output. Clark argued that rapid growth in the late 1930's unaccompanied by high investment suggested that investment could not be that important for growth. Today economists would say that high investment is not essential for a move toward full employment out of a deep depression, but may be essential to increase the level of output that could be produced at full employment.

[3]See Denison (1967), among others. The work of Jorgenson (1990) is somewhat of an outlier. Jorgenson, one of the few conducting detailed disaggregated studies of productivity growth by sector, finds that in many sectors total factor productivity growth has a strong capital-using bias, and tends to be choked off if increases in the capital/labor ratio are not forthcoming.

[4]Relatively disappointing post-World War II growth in countries like India is sometimes used to argue that machinery is not the strategic factor (see, for example, Krueger 1990). The economic disaster of the Soviet Union, an investment-intensive economy that has experienced very disappointing growth, is also often taken as evidence that a high rate of investment in physical capital does no guarantee rapid economic growth. The extent to which the Soviet Union has in fact been an investment-intensive economy is open to question. It has been a military-intensive, and also a savings-intensive, economy, but high rates of saving do not seem to have led to high quantities of physical capital that embody modern technologies.

[5]It is equally strong—accounting for 54 percent of the variance in GDP per capita growth—in the post-World War II sample analyzed by De Long and Summers.

link in the process of economic development. This paper documents macro patterns that are consistent with this view derived from the history of technology. This paper suggests that the studies of the trees carried out by technological historians like Rosenberg and his colleagues give a very good view of the entire forest as well.

III. The Data

The data base underlying the regressions in this paper paper covers six nations—Canada, Germany,[6] Italy, Japan, the United Kingdom, and the United States—and eight periods—1870 to 1885, 1885 to 1900, 1900 to 1913, 1913 to 1929, 1929 to 1938, 1938 to 1950, and 1950 to 1965, and 1965 to 1979. The countries were chosen on the basis of data availability. Long-run national income and product account estimates of the quality necessary to construct meaningful estimates of growth rates and of relative investment rates are rare. These six countries are those with the best data.

The past century was divided into fifteen-year periods, with some of the dates offset. The 1900–1913 period ends in 1913 on the eve of World War I. the 1913–1929 period ends on the eve of the Great Depression, thus containing all of World War I and subsequent business cycles leading up to the end of the 1920's boom. And the 1938–50 period ends when post-World War II reconstruction had been substantially completed.

The fifteen-year frequency of observation was chosen out of a desire to avoid confusing short-run business cycle fluctuations with long-run shifts in rates of economic growth. If the data were grouped in five year periods, or examined year-by-year, then a substantial proportion of identifying variance would come from business cycle fluctuations and generate a spurious association between investment and growth unrelated to the links between investment and long-run growth. The fifteen-year frequency of observation avoids such possible contamination.

---

[6]West Germany after World War II.

The data base covers a substantial part of the industrial world. These six countries account today for roughly sixty percent of total world economic product. Since these economies have grown somewhat faster than the world average, they accounted for a somewhat smaller share—forty percent is not an unreasonable guess—back in 1870. This span of time has seen national product per capita levels in these countries increase on average perhaps tenfold, and has seen their populations triple.

In choosing among different estimates of economic growth and investment shares, the data base underlying paper stays as close as possible to the numbers compiled by Maddison (1982). Maddison (1982 and 1989), through the database that he has compiled, has had a substantial influence on economists' and historians' conceptions of long-run growth in comparative perspective. Out of those available (see also Bairoch, 1976 and 1981), Maddison's database one of the most comprehensive and certainly the best documented. Hower, his estimates are certainly not immune from challenge.

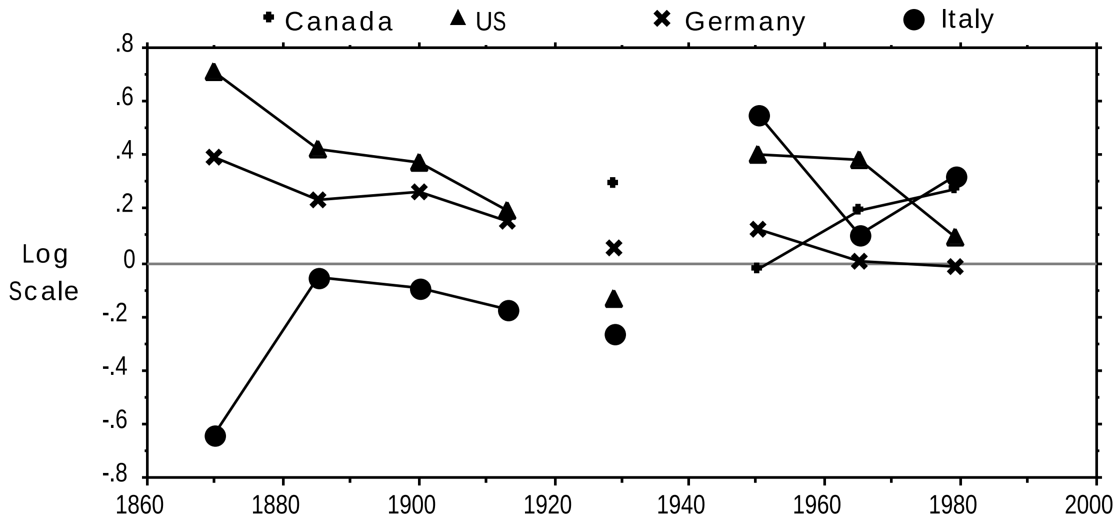
A. National Product Estimates

Nevertheless, the estimates of national product per capita growth used have been drawn entirely from Maddison (1982). Maddison's estimates of relative levels of national product are derived by extrapolating growth rates as given by separate nation-specific studies backward in time from a current benchmark. Economic growth estimates are measured using different price vectors: the relative prices in which Japanese growth from 1965–79 is calculated are *not* the relative prices in which German growth from 1900–13 is calculated. There is no good reason to believe that the different national product growth rates reported by Maddison are consistent, and there have to date been few good studies to date of the magnitude of the potential inconsistencies.[7]

---

[7]See de Vries (1984) for an argument that Maddison's estimates of Dutch nineteenth century growth are substantially awry. Future challengers and revisors of Maddison, however, must begin where his work leaves off—and his work has made that of potential revisionists much easier.

Figure 1
Real Wage/Income Per Capita Ratios Relative to Great Britain
1870–1979



One way to assess the reliability of Maddison's comparative estimates of national product per capita is to compare them to other measures of prosperity, based on contemporary data, that are not built up using the present-day benchmark and backward extrapolation procedure. Williamson (1991), for example, has recently compiled estimates of the relative real wages at purchasing power parities of unskilled workers before World War I in different countries. Figure 1 plots for four of the nations—all save Japan—the proportional divergence, relative to the United Kingdom, of the ratio of the real unskilled worker wage to national product per capita.

As figure 1 shows, in 1870 the ratio of the unskilled worker real wage as calculated by Williamson (1991) in Italy relative to Britain is little more than half—a difference in the natural log of -0.65—the ratio of real national product per capita in Italy relative to Britain as estimated by Maddison. While Maddison's estimates of national income per capita suggest that Italy in 1870 was two-thirds as wealthy as Britain, Williamson's estimates suggest that Italian real wages for unskilled workers in 1870 were one-third of contemporary British levels.[8] That at least one of

[8]U.S. especially, and also German, real wage levels according to Williamson give a more favorable view of economic welfare relative to Britain than do Maddison's national product per capita estimates. This makes sense: Britain as a land-poor country where rents were high and ownership concentrated presumably had a much more

these pairs of estimates must be misleading is suggested by the convergence of the two ratios by 1885. While the real wage measure suggests extraordinary growth over this period, the national income per capita measures suggest relative stagnation. Accordingly, Italian data from 1870–85 must be viewed with suspicion.

In the post-World War II period there is a similar potential inconsistency between wage- and national product-based estimates of prosperity in Italy relative to Britain in 1950, and a corresponding divergence between wage- and national product-based estimates of economic growth over 1950–65. Relative to Britain, Italian growth rates appear three percentage points per year more favorable if the national product-based estimates are used. In this case, the divergence probably reveals not deficiencies in national product accounts, but the state of the Italian labor market in the immediate aftermath of World War II with a strong Communist-influenced union movement, high relative wages, and high unemployment.

The conclusion to be drawn from figure 1 is, unsurprisingly, that the Italian national product data are the most suspect, and that regressions relying heavily on Italian evidence should be handled gingerly. But figure 1 gives no strong reason to believe that Maddison's methodology of backward extrapolation using growth rates from contemporary benchmarks significantly mismeasures the relative pace of very long-run growth in the U.S. and Germany relative to Britain.[9]

This would not be the conclusion reached if a significantly larger sample were examined. National income and product accounts for other nations over the very long run are significantly inferior to those for the U.S., Britain, Germany, and Canada. For example, use of data on Argentina and on Scandinavia was considered but then rejected because of the excessively shaky nature of national income and product estimates. In addition, note that there are no independent

---

skewed distribution of income in the mid-nineteenth century than did the U.S. As time passes and the U.S. becomes a more industrial nation with a more unequal distribution of income, the gap between wage- and national product-based estimates of relative prosperity in the U.S. and Britain closes.

[9]A similar conclusion could have been reached by examining Mulhall's (1896) contemporary-based estimates of the industries and wealth of nations. Excluding Japan (which Mulhall does not cover), the correlation for the sample used here between estimates of national product per capita from Maddison and Mulhall's estimates of "earnings per head" is 0.98.

sources of information on Japan. The relative consistency of Maddison's calculations of Japanese prosperity relative to European levels in the late nineteenth century remains unchecked.[10]

B. Investment Share Estimates

The estimates of the rate of investment in machinery and equipment are compiled from he individual national sources.[11] As a result, the same potential inconsistencies present in the national product estimates hold true of the investment share estimates as well. The only saving grace is that because the estimates are current levels rather than cumulative values, mismeasurement in one period does not propagate and corrupt the estimated level in earlier periods as well.

Relative price deflators used to calculate them differ, significantly in some cases, across countries and across periods. Considerable measurement error is implicit in *all* of the estimates used. This paper is worthwhile only to the extent that such measurement error does not corrupt the conclusions. The database presented here should not be used to draw conclusions about the characteristics and pattern of growth in any one country relative to other countries in the sample.

As the number of observations increases, however, the impact of mismeasurement in the data diminishes. Statements about the deviations of national growth patterns from the average pattern found in the sample derived from the data used in this paper may well be significantly misleading. However, conclusions about the characteristics of the long-run growth process in the

---

[10]De Long (1988) makes some skeptical observations on some of the estimates in Maddison (1982), particularly those for Japan and Scandinavia.

[11]Sources of pre-World War II data on capital stock estimates and investment shares are as follows. For Canada, only official post-1929 data are available. A more detailed picture of earlier growth could be constructed by extrapolating from the individual years covered by Firestone (1953), but I believe that the data will not bear the weight of such extrapolation. For Germany, the estimates used are Maddison's (1982) revisions of Hoffman *et al.'s* (1965) estimates. Before 1929, the underlying estimates of the German capital stock are "net concept" estimates. All other estimates used are "gross concept" estimates. Italian machinery and equipment data are derived from Fua (1964) for the pre-World War II period, and from Summers and Heston (1991) thereafter. Japanese data are derived from Ohkawa (1966) for the pre-World War II period, and from Summers and Heston (1991) for the post-World War II period. United Kingdom data are taken from Feinstein (1972). For the United States, the estimates for the post-1929 period are the official Department of Commerce estimates; the estimates for the pre-1929 period are derived from Kuznets (1962).

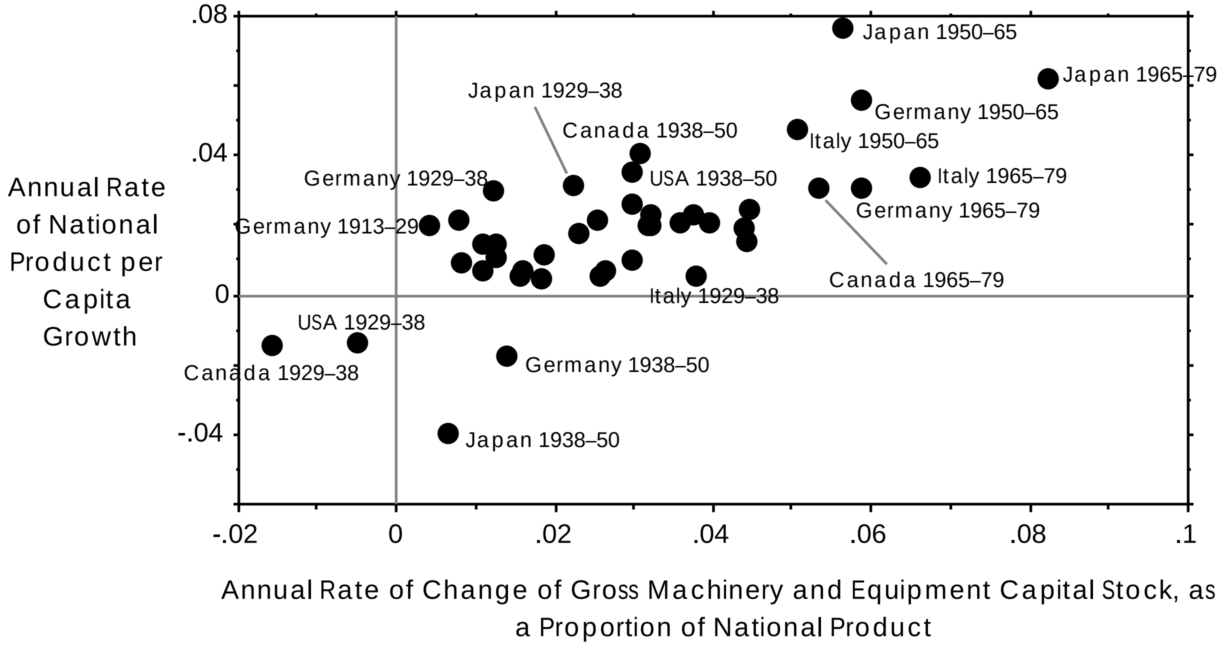
"typical" presently-industrialized nation are more secure, for errors in estimating the experience of individual nations will tend to cancel to some degree when averages across nations are considered.

The investment estimates used in this paper are equal to new investment less retirements. It is thus larger than is calculated according to the "net investment" concept, which subtracts depreciation on currently-installed and useful capital. It is smaller than the "gross investment" concept, which does not subtract but ignores retirements. The concept used here has the advantage that its series cumulates to the level of the gross capital stock—which gross investment does not—and so it is possible to check flow-derived estimates of investment for consistency against independent point in time estimates of national capital stocks. It has the second advantage that it is the concept appropriate for aggregate production function analyses: it is the change in units of physical capital available for use in the production process.

IV. Equipment Accumulation and Productivity

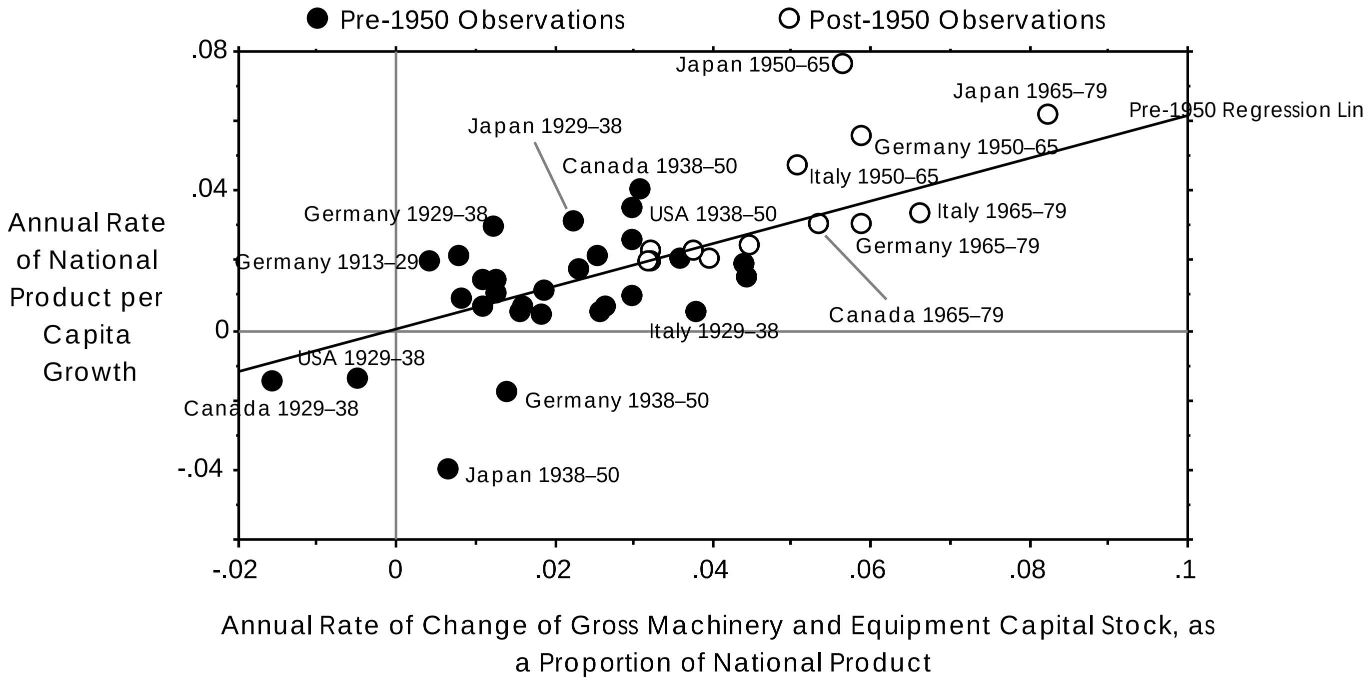
Figure 2 below plots the simple scatter of average gross machinery and equipment investment shares of national product against the growth rate of national product per capita. The association is strong and positive. It accounts for more than half of the variance of national product per capita growth rates. It would correspond to a t-statistic of 7.3 under the (false) assumption that residuals are independently distributed. The regression coefficient is large in magnitude: each one percentage point rise in the equipment investment share of national product is associated with an increase of 0.70 percent in national product per capita growth rates.

Figure 2
Scatter of Equipment Investment and National Product per Capita Growth



In figure 2 the highest-growth highest-equipment investment points all come from the post-World War II era. This “Great Keynesian Boom” was a period of rapid growth and accumulation at a pace significantly faster than the industrial economies had previously seen. This raises the possibility that World War II marks a structural break, and that the association between equipment investment and economic growth is not a robust feature present in either or both of the pre- and post-World War II eras, but is just a reflection of this structural break.

Figure 3
Equipment Investment and Productivity Growth Pre- and Post-1950



This issue is resolved to a degree by figure 3. Figure 3 graphs the simple bivariate regression line for the earlier pre-1950 periods. The post-1950 data points fall squarely on the regression line predicted from the pre-1950 observations. Six of the 1950–79 data points have more rapid, and six have less rapid national product per capita growth than would have been expected given actual post-1950 rates of equipment investment and the pre-1950 relationship.

Table 1
GDP per Capita Growth Regressed on Machinery and non-Machinery Investment Rates

Specification	Equipment Investment	Non-Res. Const.	Extra Effect of Equipment: T-Statistic	Population Growth	Level Relative to U.S.A.	R^2	SEE
Full	0.561 (0.157)	0.192 (0.117)	1.47	-0.481 (0.504)	-0.011 (0.009)	0.587	0.0139
Full	0.624 (0.147)	0.167 (0.115)	1.91	-0.543 (0.504)		0.572	0.0140

Full	0.599	0.127	2.10		-0.011	0.577	0.0139
	(0.151)	(0.094)			(0.009)		
Full	0.675	0.101	2.07	-0.373	-0.049	0.665	0.0135
Nation Dummies*	(0.169)	(0.129)		(0.609)	(0.021)		
Full	0.714	0.117	2.03	-0.800		0.607	0.0144
Nation Dummies	(0.179)	(0.137)		(0.620)			
Full	0.736	0.175	1.80	-0.741	-0.003	0.640	0.0144
Era Dummies**	(0.225)	(0.138)		(0.644)	(0.011)		
Full	0.770	0.169	2.21	-0.772		0.639	0.0142
Era Dummies**	(0.196)	(0.135)		(0.627)			
Full	1.227	0.046	3.35	-2.212	-0.031	0.758	0.0130
Nation & Era***	(0.266)	(0.140)		(0.907)	(0.026)		
Full	1.311	0.043	3.65	-2.516		0.744	0.0131
Nation & Era***	(0.259)	(0.142)		(0.876)			

*The U.S. alone has a significant nation dummy: +0.0208.
**None of the era dummies are significant.
***The 1965–79 era coefficient has a significant negative coefficient, the Canada and the U.S.A. nation coefficients are significant and positive.

Note, moreover, that little of the rapid post-1950 growth in national product per capita or of the high pace of investment in equipment and machinery can be attributed to efforts to regain and replace wartime losses. Only Japan and Germany were below their pre-World War II growth paths by 1950, and they were not far below. By 1965, all six of the countries were above not only their pre-World War II but also their pre-Great Depression growth paths.[12]

Table 1 reports regressions that document in more detail the associations of national

[12]See Milward (1984), or De Long and Eichengreen (1991), for the pace of post-World War II reconstruction.

product per capita growth and investment in machinery and equipment. Table 1 adds as controls several additional independent variables: the level of national product per capita relative to the United States in order to take account of possible "convergence" as follower countries are able to more quickly retrace the steps of industrial leaders, the rate of population growth to take account of additional burdens placed on the economy by the requirements of capital widening, the share of non-residential construction investment in national product to control for the increase in productivity produced by other forms of investment besides equipment, and separate indicator variables for each nation and era to partially control for the host of additional influences, nation- and era-specific, on the rate of economic growth. Table 1 also reports, in its third column, the t-statistic on the difference between the coefficient estimated for investment in machinery and equipment and the coefficient estimated for investment in non-residential construction.

In table 1, growth has a significantly closer association with investment in machinery and equipment than with investment in non-residential construction. Consider just the first regression in the table, with the lowest t-statistic on the difference between the coefficients on machinery investment and on non-residential construction investment: 1.47. A rational observer who originally thought that the odds were even that machinery had a stronger association with growth than other investment would, if the first regression in table 1 came as completely new information, believe after seeing the regression that the odds were 6-1 that machinery had the stronger association with growth.

The nation and era indicator variables introduced into the regressions do not alter the broad qualitative pattern.[13] Equipment investment remains highly associated with national product per capita growth, and it remains more closely associated with national product per capita growth than is investment in non-residential structures. Moreover, the nation and era indicator variables rarely carry statistically significant coefficients. The U.S.A. indicator is one of the few exceptions: the U.S.A. has grown over the past century about two percent per year

---

[13] Nation effects are measured relative to Germany. Era effects are measured relative to the initial 1870–85 period.

faster than would be expected given its level of per capita national product relative to the other industrial nations and its rate of equipment investment.[14] A second exception is the Canada indicator variable, which is significant in two of the eight regressions. The last significant indicator is for 1965–79; the variable is significant and negative in two of the regressions.[15]

It is interesting that there are not significant nation and era effects in the relationships reported in table 1 and plotted in figures 2 and 3. Such nation and era effects would presumably proxy for important omitted variables—like rates of education, impacts of regulatory economic policies, or the functioning of the international economic régime—that had differential effects across nations and eras. Such omitted variables do not appear to be important in this data set. There are almost surely other important determinants of economic growth rates other than the increase of population, the accumulation of capital, and "catch-up" derived from initial relative backwardness. But such other determinants are neither persistent within any particular nation or set of nations, nor are they pervasive across the set of industrial nations in any one era.

Regressions with the nation and era indicator variables included generate very large coefficients on the equipment investment variable. This may arise because the indicator variables soak up too much of the long run identifying variance in the data set, leaving too great a role for business cycle movements in investment and in output relative to potential rather than shifts in the level of potential output itself.

This is particularly likely to be the case in the 1913–29 and 1929–38 periods which cover the boom of the 1920's and the subsequent Great Depression. For this reason more reliance should be placed on the regressions without nation and period indicator variables. They give higher weight in estimation to the long-run movements in production and capital and lower

---

[14] The first of these factors is the important one. When the level of national product per capita relative to the U.S.A. is dropped from the list of independent variables, then the U.S.A. indicator variable loses its significance. Thus the positive and significant indicator arises because the U.S.A. is an exception to the "convergence" toward average productivity levels for the set of industrial nations as a whole that is exhibited by other industrial economies. Thus U.S.A. has managed to maintain its productivity lead for an astonishingly long time. See Abramovitz (1986), and Baumol, Blackman, and Wolff (1989). The positive U.S.A. indicator variable reveals not so much that the U.S.A. has grown faster than expected given its rate of machinery investment but that it has grown faster than expected given its relative wealth.

[15] This may be due to the disturbances that affected the world economy in the 1970's.

weight to business-cycle movements. And the small size of the estimated nation and period indicator variables suggests that their omission does not significantly bias the machinery investment coefficient estimates. The grouping of the data into fifteen-year periods was intended to minimize the effect of business cycle fluctuations on the regression coefficients, but is an imperfect makeshift.

V. Causality

Few would argue that equipment investment is exogenous with respect to growth in national product per capita, even over the very long run. Almost any residual influence generating faster economic growth will also raise profits, both on average and at the margin. If such an increase in profits is anticipated by investors, it may well lead them to invest more in anticipation of higher future returns. The association between machinery and equipment investment and national product per capita growth documented in figures 2 and 3 and in table 1 might well fail to be a causal relationship.

A. Intensive and Extensive Growth

One piece of evidence that suggests that the primary causal links run from high equipment investment to rapid growth comes from exploiting the distinction between national product growth and national product per capita growth. If faster growth caused by other, external factors leads to higher investment rates because of the expectation of higher future profits, there is no clear reason for investment no to respond equally to increases in national product generated by productivity and increases generated by population. Faster growth leads to higher investment because faster growth generates a larger and richer market, and it presumably should not matter much whether that larger and richer market comes from having more consumers or richer consumers.[16] Only if the wealth elasticity of demand for products made by machinery was significantly greater than one would the distinction between productivity growth and population growth make a significant difference under investment demand-driven explanations of the correlation of machinery investment and productivity growth.

Table 2 regresses equipment investment rates on national product per capita and population growth rates for the entire database. These regressions show a strong association between national product per capita growth and equipment investment, and a weaker and imprecisely estimated association between population growth (holding national product per capita constant) and equipment investment.

Rapid growth—either in the form of national product per capita growth (holding population constant) or in the form of population growth (holding national product per capita constant) is indeed associated with higher rates of investment. But *intensive* growth that raises productivity and income levels is especially strongly associated with equipment investment.

Table 2
Equipment and Non-Equipment Investment Rates Regressed on National Product per Capita Growth and Population Growth

Dependent Variable	National Product per Cap. Growth	Population Growth	Structures Investment	R^2	SEE
Equipment Investment	0.710 (0.104)	0.319 (0.383)		0.556	0.0137
Equipment Investment	0.513 (0.121)	-0.459 (0.458)	0.265 (0.098)	0.627	0.0127

Long-run wealth elasticities of demand are hard to estimate because large changes in wealth levels are almost always associated with large changes in relative price structures as well.

[16]This insight is due to Barry Bosworth, who suggested that De Long and Summers (1991) use this procedure to try to identify causality in the post-World War II period.

But it is at least plausible to argue that the long-run wealth elasticity of demand for manufactured goods produced by machinery-intensive production processes is not far from one, in which case population growth and output per capita growth should have similar effects on the derived demand for machinery and equipment. Table 2 is therefore evidence that a component of the association between national product per capita growth and equipment investment is driven by a causal link from equipment investment to growth.[17] However, it is only weak evidence because there is not enough variation in population growth rates to precisely estimate the association between population growth and equipment investment.[18]

B. Human Capital Accumulation

A second piece of evidence that the primary causal links run from machinery to growth is to examine the effect of adding to the regression other variables correlated with non-machinery driven increases in productivity. The most obvious such variables are education: the proportion of the population in school, and the proportion of the population receiving higher education.

Table 3
GDP per Capita Growth Regressed on Machinery Investment and Education Variables

Specification	Equipment Investment	Non-Res. Const.	Initial Level of Education*	Education Growth	HIgher Educ. Growth	R^2	SEE
Japan Omitted	0.607	0.039	0.0020			0.562	0.0113
	(0.125)	(0.089)	(0.0070)				
Japan Omitted	0.751	0.040		-0.252		0.601	0.0113
	(0.149)	(0.079)		(0.142)			
Japan Omitted	0.786	0.041			-0.183	0.620	0.0116

[17]When nation and era indicator variables are added to regressions like those of table 2, coefficients are not estimated precisely and are not significant.

[18]De Long and Summers (1991) previously carried out the same test on a post-World War II data base with much more variation in population growth rates. They did find statistically significant differences between the partial associations of equipment investment with productivity and population growth

	(0.156)	(0.082)		(0.081)		
Japan Omitted	0.705	-0.008	0.0014		0.583	0.0121
Nation Dummies**	(0.204)	(0.136)	(0.0114)			
Japan Omitted	0.732	-0.022	0.0072		0.620	0.0120
Period Dummies***	(0.220)	(0.134)	(0.0098)			
Japan Omitted	0.901	-0.050	0.0063		0.653	0.0127
Nation & Era…****	(0.277)	(0.169)	(0.0149)			

*A time trend is also included as an independent variable.
**None of the nation dummies are statistically significant.
***None of the period dummies are statistically significant.
****Neither the nation nor the period dummies are statistically significant.

Table 3 reports sample regressions of GDP per capita growth on equipment investment when variables measuring the extent of formal education are added to the specification. The log of the fraction of the age-appropriate population receiving schooling is never significant when added to the regression whether or not a time trend and period indicator variables are included. Its coefficient is also small in magnitude. A doubling of the school attendence rate increases the rate of growth of GDP per capita by at most 0.7 percentage points per year. Other educational variables are less successful as independent determinants of growth rates in this dataset. The proportional rates of growth of the fraction of the population receiving education and of the fraction receiving higher education have negative—that is, wrong—signs.

The magnitude and significance of the machinery and equipment investment coefficients are unaffected by the inclusion of the education variables. The closeness of the association between investment in machinery and equipment and productivity growth conditional on the inclusion of previously-omitted variables like education suggests that the tight association between equipment investment and long-run economic growth does not arise from the omission of the true causes of growth.

C. Post-World War II Evidence

A third important piece of evidence is the recent, post-World War II experience. It is can be useful to examine the present with an eye toward what it reveals about structural relationships that may well have held in the more distant past also: to "write history backwards"[19] by using what is known about the recent past and about the dynamics of structural change to infer the likely shape of eras more distant in time.

The database constructed by Summers and Heston (1990) has proven an excellent resource for cross-nation looks at long-run growth in the post-World War II period (see Dowrick and Nguyen, 1989; De Long and Summers, 1991). If structural characteristics did not radically and suddenly change in the first years after World War II, then the behavior of economies since World War II has the potential to reveal much about their behavior before.

Confidence in the association between machinery investment and productivity growth over the very long run is therefore strengthened by the presence of a strong association in post-World War II data as well. In a post-World War II cross section of more than sixty nations,[20] each one percentage point increase in the equipment investment share of GDP is associated with a 0.3 percentage point increase in the annual rate of GDP per capita growth, and accounts for 31 percent of the variance of growth rates (De Long and Summers, 1991). Other variables included—initial GDP per worker levels, labor force growth rates, and non-machinery investment rates—account in total for less than 5 percent of the variance of growth rates. Figure 3 shows the partial scatter of equipment investment and productivity growth—the relationship between the two variables controlling for all other variables[21] in the regression.[22]

---

[19]See Kelley and Williamson (1971).

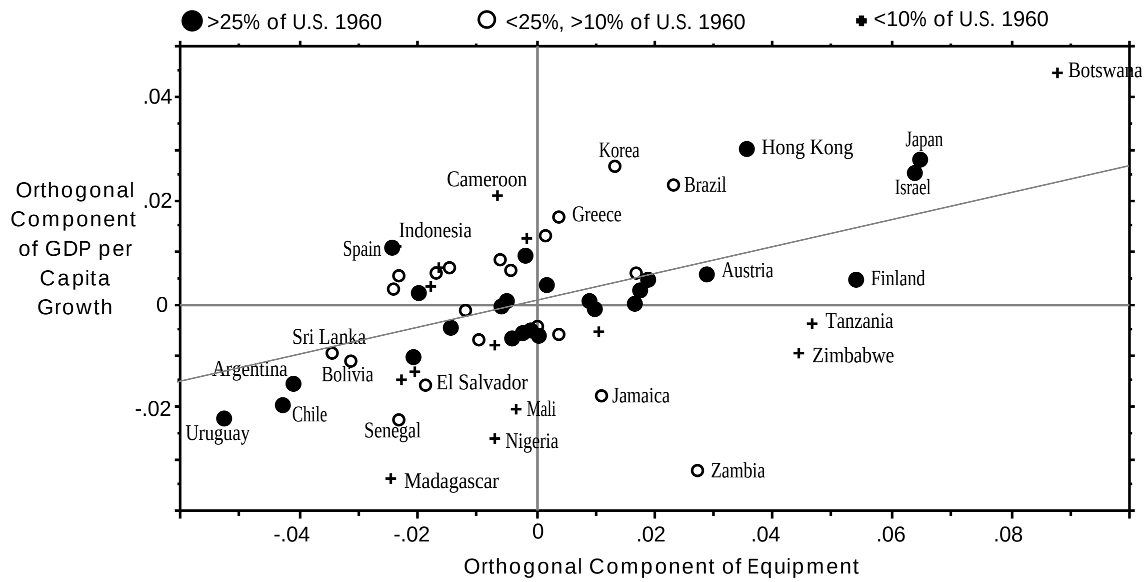
[18]See Summers and Heston (1984 and 1991).

[21]Non-machinery investment, the rate of population growth, and the initial level of GDP per capita.

[22]Jones (1991) reports similar findings using the same data set. Since Jones worked independently and chose different specifications, his reporting of similar results lends confidence that the association between equipment investment and growth is robust. Jones places much more stress on prices of machinery and equipment as signals guiding the economy and thus stresses the importance of getting the relative price of producer durables right—i.e., low; De Long and Summers place much more stress on quantities of machinery and equipment.

De Long and Summers (1991) and Jones (1991) argue that there is a strong case that the post-World War II association between equipment investment and growth is itself causal. The piece of evidence they stress the most is that in the post-World War II period high machinery investment is strongly correlated with low prices for producer durable goods. It is hard to see how rapid growth driven by independent causes would reduce the prices of producer durables. And it is easier to see how a low price of producer durables leads to high machinery investment, and to rapid growth.[23]

Figure 4
Partial Scatter of Productivity Growth Rates and Equipment Investment Shares of National Product



Even a completely successful demonstration that higher equipment investment drove faster economic growth in the post-World War II period does not necessarily show that higher machinery investment drove faster economic growth in the very long run as well. Such a

---

[23]Two other pieces of post-World War II evidence also support such a conclusion. First, as noted above, in the post-World War II period machinery investment is more closely associated with intensive growth than extensive growth. Second, instrumental variables tests show that various distinct components of equipment investment—the component associated with low producer durable goods prices, the component associated with high national savings rates, and the component associated with a perceived favorable business climate—all have about the same association with labor productivity growth. If faster growth triggers higher investment, it would presumably work most strongly on one of these components—that associated with high savings rates—and less strongly on the others.

conclusion is an inference, based on a willingness to “write history backwards.” Nevertheless, it is a reasonable inference.

D. Case Studies: Argentina and Germany

A fourth path of argument supporting the claim that the association between equipment investment and growth is causal comes from examining case studies. In particular individual nations the course of economic history and economic policy may be such as to resolve issues that regression analysis cannot touch. This subsection considers two cases: the collapse of Argentinian growth and the acceleration of West German growth after World War II. It argues that in Argentina it is clear that low investment is a product of economic policies and not a reaction to slow growth. And it argues that in Germany fast growth was a surpise, and so German businessmen did not strongly in the 1950’s in anticipation of the ongoing *Wirtschaftswunder.*

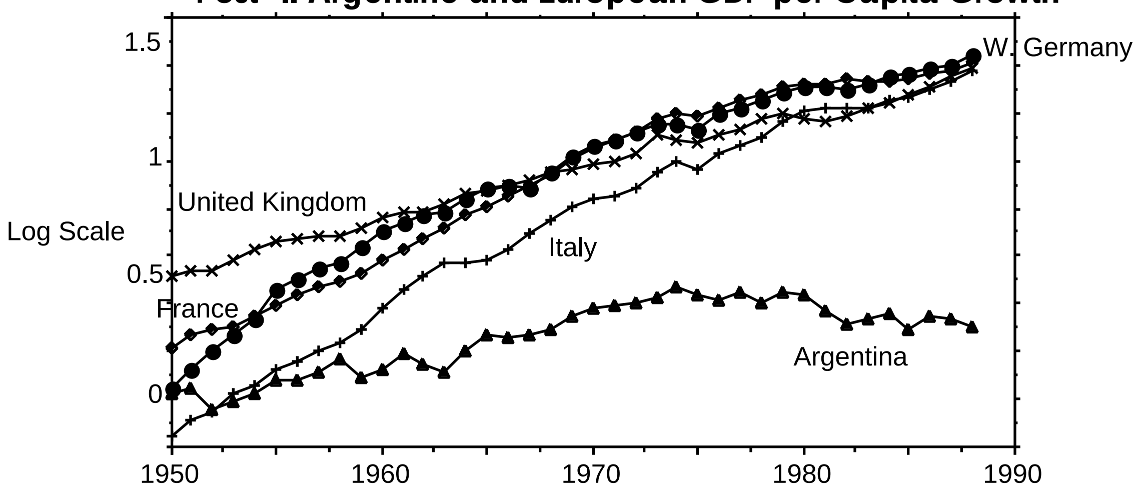
1. Argentina

The long-run national income and product accounts of Argentina are not sufficiently detailed are reliable for its inclusion in the database underlying the regressions. Neverthless, it makes a fascinating case study. For up to the late 1950’s, Argentina was a country as rich as any in continental Europe. In 1929 Argentina had been perhaps fifth in the world in automobiles per capita. In 1913 Buenos Aires had been perhaps thirteenth among cities of the world in telephones per capita. Yet by the late 1970’s—even before the Latin American debt crisis and the subsequent decade of decline in the 1980’s—Argentina had become a third world rather than a first world country (Díaz-Alejandro, 1970). Figure 5 (from De Long and Eichengreen, 1991) plots the relative erosion of Argentine national product per capita levels from levels comparable to continental Europe at the end of World War II to levels an order of magnitude beneath the European standard today.

Díaz-Alejandro (1970) provides the standard analysis of the relative economic decline of

Argentina. The Great Depression had left Argentina justifiably suspicious of the free-trade order, for its commitment to openness and integration into the world economy had not been matched by its trading partners, which had taken aggressive steps to shut Argentina out of their domestic markets and so preserve employment at Argentina's expense. Moreover, the Great Depression had led to sharpened lines of political cleavage. Landowner and exporter elites had shown eagerness to sacrifice political democracy in order to stunt and roll back the growth of the welfare state.

Figure 5
Post- II Argentine and European GDP per Capita Growth



In this environment Juan Perón gained mass political support for a program of strong national reassertion and populist income redistribution. He argued that the previous half-century of Argentine prosperity had for the most part enriched rural oligarchs and foreign exporters; he sought a more equal distribution of the fruits of Argentine prosperity. To achieve these ends—and also to reward politically-powerful urban working classes who had provided the bedrock of his support, and whose demonstrations had led to his release from prison and accession to power. Agricultural marketing boards were established to limit the price of food, the growth of unions and the organization of workers was supported, urban real wages were boosted, and protection against foreign manufacturers was introduced.

Perón sought both to generate rapid economic growth, and to twist the terms of trade against rural agriculture. This would redistribute wealth to urban workers who had not before received their fare share. It would also redistribute wealth toward established businessmen—in order to protect the jobs of their employees who were now receiving higher real wages—and away from exporters, agricultural oligarchs, foreigners, and nascent entrepreneurs.

The Perónist program of Keynesian stimulation, price controls, and wage increases produced almost half a decade of very rapid growth. But then exports fell sharply as a result of the international busines cycle. The resulting foreign exchange shortage provided Perón with only unattractive options. The first option was one of devaluation, cutting living standards by raising the price of imported goods and setting off a wave of inflation. But such a policy would not immediately close his balance of payments gap, and the adjustment assistance from outside necessary to make a policy of devaluation possible would be forthcoming only if Perón adopted more "orthodox" economic policies. Such an option was unthinkable to a strong nationalist.

The second option was one of internal austerity, using monetary and fiscal contraction to reduce demand, raise unemployment, and so balance foreign payments. This was equally unacceptable: prior only to assertions of national independence in Perón's politics was the granting of their fare share to the urban working class on whom policies of internal austerity would weigh most heavily.

The third option was the imposition of controls on imports, to balance his foreign payments by restricting and rationing whole classes of imported goods. Perón and his advisors chose this third alternative, believing that a dash for growth, a maintenance of his redistributive policies, and a reduction in dependence on the world economy was good for Argentina.

Foreign exchange was rationed. First priority went to raw materials to keep factories operating. Second priority went to goods imported for home consumption to keep urban workers' living standards high. Third and last priority went to imports of key capital goods for investment and capacity expansion.

As a result, the early 1950's saw a huge rise in the relative price of capital goods. Before

1945 Argentina's relative price structure had been about average for a country of its level of wealth and industrialization. By the early 1950's the relative price of producer durable goods in Argentina was two or three times world levels.

In post-World War II Argentina, therefore, each percentage point of national product saved and committed to the purchase of machinery and equipment led to only one-third to one-half of a percentage point's worth of real investment in machinery and equipment. Díaz-Alejandro found that "[r]emarkably, the capital stock in electricity and communications increased by a larger percentage during the depression years 1929-39 than during 1945-55," even though the 1945–55 government was the one that boasted of encouraging industrialization.

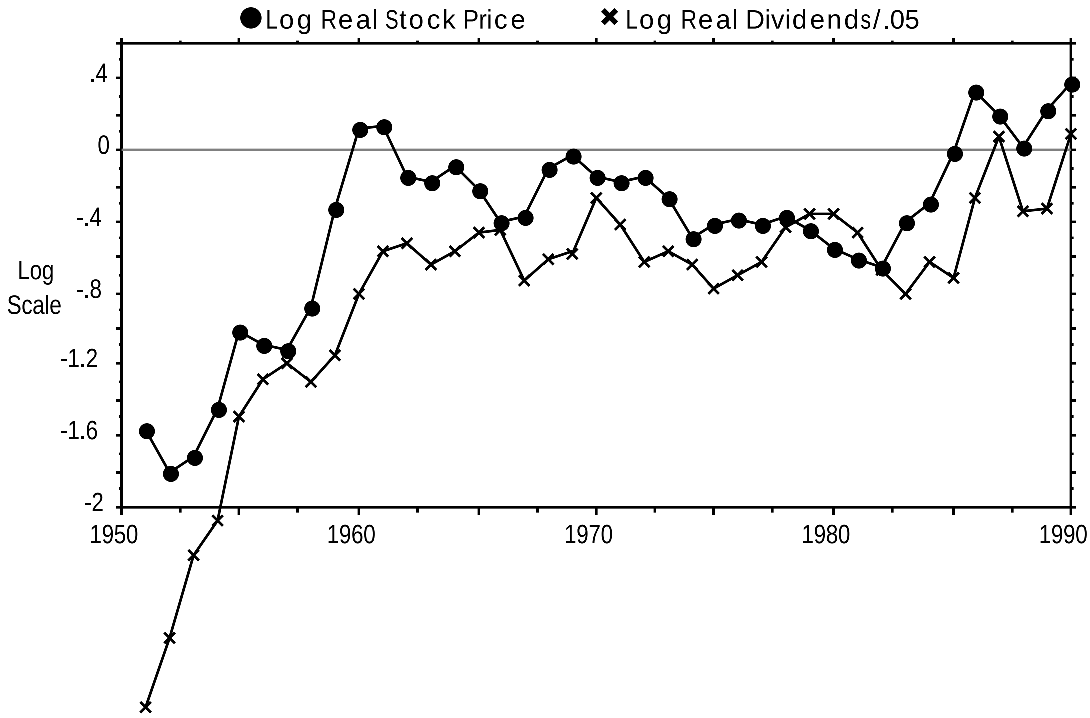
Subsequent governments moderated but did not rollback Perónist policies. The interest groups that he had mobilized remained, and remained powerful. Argentinian equipment prices have remained extraordinarily high—and thus, in spite of a healthy domestic savings rate, Argentinian rates of investment in machinery and equipment have been extraordinarily low—throughout the post-World War II period. The economy has stagnated. In this case, low equipment investment can be almost immediately traced to governmental economic policies, and so cannot be a consequence of slow Argentinian growth.

2. Post-World War II West Germany

The case of post-World War II Argentina finds its exact opposite in the case of post-World War II West Germany. Post-World War II Argentina was thought to have a bright economic future. Post-World War II West Germany was often seen as likely to require more than a generation to regain anything close to its previous relative economic position. Yet as figure 5 shows, between 1950 and 1960 West German national product per capita gained 35 percent relative to France and 45 percent relative to Britain, leaving it with levels of productivity about halfway between the two.

Figure 6 plots the course of the real value of the West German stock market over the post-World War II era (from De Long and Becht, 1991). Real values rise very rapidly from 1951 to 1960, by a cumulative factor of more than six over the decade. Real dividends rise by much more relative to their early 1950's levels: by a factor not of six but of twelve.

Figure 6
German Real Stock Market Value and Dividends for the Post-World War II Period



During the nine years from 1951 to 1960, the average real rate of return earned on the German stock market was twenty-four percent per year. This was the decade that saw German economic growth take its major leap. The very high realized rates of return on the stock market during this decade indicate that the major proportion of this economic growth leap was *unanticipated.* Had investors foreseen the rapid growth of the German economy that did in fact occur over the 1950's, they would have bid stock prices up to much higher levels in the early 1950's in anticipation of such growth. Those who did forecast rapid growth and did invest in anticipation made a killing. But the market's low valuation of German companies in the early 1950's indicates that anticipation of the magnitude of the *Wirtschaftswunder* was the exception, not the rule in post-World War II Germany.

The evidence from the stock market reveals that in the case of post-World War II Germany in the 1950's it is not possible to ascribe high equipment investment to anticipations of rapid economic growth in the future, for by and large Germans did not anticipate the bright economic future that lay ahead. If Germany's high rate of investment in the post-World War II period is related to its economic miracle, it is as cause rather than consequence of rapid growth.

VI. Technology and Productivity

The previous sections have sketched a macroeconomic pattern of a powerful, and presumably causal, relationship between equipment investment and economic growth. This pattern is consistent with a view of the microeconomics of technological adaptation that stresses the continuity of technological development, and the importance of hands-on experience: "continuity" in the sense that most of productivity growth is the result not of single, discrete, major inventions or borrowings but rather of a continuous and ongoing process of improvement and adaptation, no one step in which is particularly important or noteworthy; "experience" in the sense that skills needed to handle and productively use modern technology are most easily and rapidly gained by using modern technology.

A. Continuity

A number of historians of technology have noted that productivity improvement is a continuous and incremental process, separate from the "inventions" that are recorded in popular histories and histories of science. [24] As Rosenberg (1976) puts it: "…most inventions are relatively crude and inefficient [at first].…They are, of necessity, badly adapted to many of the ultimate uses to which they will eventually be put…they offer only small advantages, or perhaps

---

[24]Rosenberg (1978) excellently surveys work on the history of technology. Rosenberg's survey was written too early to cover David Hounshell's (1984) *From the American System to Mass Production.* This is its principal deficiency from the standpoint of today.

none at all." Rosenberg concludes that "the pace at which subsequent improvements are made will be a major determinant of the rate of diffusion. He quotes Enos (1958) to the effect that "improving a process contributes even more to technological progress than does its initial development."

Consider three exemplary case studies. First, consider productivity growth in the American railroad industry. Fishlow (1966) finds that over the forty years from 1870 to 1910 the lion's share of cost reduction was contributed by incremental changes in the design of freight cars and locomotives. One by one, these changes were small and barely noticed. But over forty years they added up to a doubling of the effective power of locomotives and to a tripling of the capacity of freight cars.

Second, a similar pattern holds in the past two decades in the computerized tomography scanner industry.[25] The initial invention had relatively small effects. It was the explosion of incremental improvements and developments in the next decade—themselves separate from although unthinkable without the initial invention—that contributed the lion's share of the value of the innovation.[26] These incremental improvements consisted both of improvements in the workings of the scanner, and in the addition to the scanner of those features that doctors found most useful in practice.

The third case study is the development of the steamboat in the United States. Hunter (1949) notes that in 1840 there were operating in the western United States 540 steamboats grossing 83,000 tons, and that steamboats accounted for perhaps sixty percent of all power generated by steam engines in the United States. Both the steam engine and the principles of ship design were technological borrowings from Britain: United States inventors played little part in the origination of the fundamental technologies used. Yet, as Rosenberg (1972) reflects:

---

[25] See Trajtenberg (1990).

[26] Similar patterns can be found even in technologies that appear at first glance stable. Rosenberg (1982) makes this point for a single type of aircraft, the DC-8: "[i]n this aircraft," he writes, "operating energy costs…on a per-seat-mile basis have been reduced by 50 percent, even though the basic configuration has remained largely unchanges and the modifications have been relatively unsophisticated."

> If one asks precisely what it was which was "acquired" from the Old World, the answer is by no means obvious.…[T]he steamboat at the time of its inception was a clumsy merger of the steam engine with an ordinary ocean-going vessel…remarkably ill-adapted to the shallow-water navigation of inland rivers. The transformation of the basic design occurred very quickly, and yet it is difficult to identify this transformation with specific inventions…

By 1830 the steamboat was no longer powered by a costly to build fuel-efficient low-pressure British steam engine, but by a cheap to build—and to repair—fuel-wasting high-pressure steam engine of American design. It had changed from a heavy-framed vessel designed to ride the waves with a projecting keel, a deep hull, and a low superstructure to a flat-bottomed shallow-drafted high-superstructure vessel. Rosenberg calls the result "a unique instrument ideally suited to a particular set of economic and geographic circumstances" which was the result of an "innumerable… continuous [series of] changes in structural design and proportions."

This brief summary of case studies cannot prove a general trend. Nevertheless, it is worth noting that historians who have examined the process of technological development have for the most part stressed not the individual acts of genius emphasized in general histories or histories of science but the process of feedback and incremental improvements in operation and design.

A similar stress on incremental improvements can be found in studies of technology adaptation by countries not at the forefront of invention and innovation. Rosovsky (1972) lays stress on Japanese excellence in what he calls "improvement engineering" in creating its ability to rapidly assimilate industrial technology. "The successful transplantation of a technology involves the domestic capacity to alter, modify, and adapt in a thousand different ways—often…subtle and evident only to a person with considerable technical expertise…[N]ew techniques frequently require considerable *modification* before they can function successfully.…This process…involves a high order of skill and ability, which is typically underestimated or ignored."

B. Utilizing Technology

How are such incremental improvements made? Clearly they can only be made by those who are already very familiar with the technology and its uses. Without workers and managers with hands-on experience the process of technology transfer and technological adaptation becomes impossibly difficult. This second point—the importance of worker and engineer experience—is worth reinforcing by outlining three additional case study examples. First, Rosenberg (1978) notes that “even when Great Britain, ‘the workshop of the world’, purchased a large quantity of American gun-making machinery in the 1850’s for introduction into the government arsenal at Enfield, American machinists and supervisory personnel had to be employed…” to teach the British workers how the new, improved machines should be used. It was easier and more complete to teach by example than through formal education or through technological literature—even though the workforce (at British military arsenals) was thoroughly familiar with modern technologies, and belonged to the most machine-intensive society in the world.

Such a pattern is not peculiar to the adoption of the “American system” of nineteenth-century manufacturing. A second example comes from the transfer of cotton spinning technology to the United States from Great Britain. The Browns of Rhode Island had seized upon a recent immigrant from Britain—Samuel Slater, who had previously had intensive experience in the British industry—to copy British machinery and construct the first textile mill in the United States after attempts to do so employing engineers without hands-on experience with the technology had proven unsuccessful. The most important knowledge about how the high-tech textile mills of 1800 worked could, it appears, be efficiently gained only through experience, and transmitted only by hands-on teaching.[27] Abundant capital, cheap and literate labor, and a high

[27]In a similar fashion, proprietors of the Boston Manufacturing Company—the first textile mill in Massachusetts—had found that the blueprints and drawings of textile machinery that Francis Cabot Lowell had surreptitiously made on his trip to England were not sufficient. They imported an engineer, Paul Moody, who had substantial experience in British textile mills, to the textile cities of Waltham and later Lowell, Massachusetts. They gave him a sizeable equity stake in the mills. And in the end they named the main street of Waltham, running in front of the mill, Moody Street.

tariff to guarantee control of the domestic market were not sufficient without the addition of technicians and managers with intensive hands-on experience using the new industrial technology.[28]

A last example comes from Porter (1990), who, drawing on van der Linde (1990) and Wolf (1981), narrates the growth and development of the German printing press industry in the nineteenth century. According to Porter, as many as four of the six leading competitors in the German printing press industry in the 1930's could trace their founding back through a chain to the original firm of Koenig and Bauer, which had built the first cylinder-based printing press in 1812 in London and had then moved to Germany. In the case of each new firm, a founder had spent years as a foreman or a mechanic in an earlier firm—or was the brother or nephew of a partner of an earlier firm.

Porter's narrative sketches the family tree of German printing press manufacturing firms over the nineteenth century. Porter argues that the location of the German industry even in the 1930's and its present-day preeminence all sprung from the original decision by Koenig and Bauer to locate in the suburbs of Würzburg—chosen because the Bavarian government provided large subsidies and helped them locate an abandoned monastery to use as a factory.

VII. Strategic Factors in Economic Growth

The macro association of machinery investment and growth and the micro case studies from the history of technological development may all be pieces of the same puzzle. On the macro side, the acquisition and installation of machinery is associated with rapid productivity growth. It appears to yield social benefits to the economy in terms of higher productivity that dwarf the profits that the owners of the capital goods installed are able to privately appropriate.

[28]A similar process was at work in the transfer of British technology to Europe. Landes (1969) counts at least 2000 skilled British workers on the Continent providing assistance in adopting new techniques. Landes observes that "perhaps the greatest contribution of these immigrants was not what they did but what they taught.…The growing technological independence of the continent resulted largely from the man-to-man transmission of skills…" which took place not in the classroom but on the job.

On the micro side, active experience with technologies is a necessary prerequisite to developing them further or to using them productively. The micro case studies would lead one to suspect that macro studies would show a strong association between machinery and growth. The macro associations would lead one to suspect that existing, installed machinery has a key role to play in productivity growth at the micro level. Both these expectations are confirmed.

A. Interpretations

The association between equipment investment and productivity growth is very strong. Estimates for the post-World War II period suggest that each additional one percentage point of total output devoted to investment in machinery and equipment raises output per worker growth by one-third of a percentage point per year—an implied real social rate of return on equipment investment of thirty percent per year or more. Estimates for the entire past century reported here suggest an effect at least as large: each additional one percentage point of total output devoted to investment in machinery and equipment raises output per worker growth by more than half a percentage point per year. Each one percentage point of output devoted to equipment investment each year appears to raise the level of total factor productivity by about four-tenths of a percent.

There are reasons to think that this is perhaps an overestimate. The nations in the sample all, today, possess very wealthy and successfully industrialized economies. Circumstances have broken in their favor over the past century. The high coefficient may to some degree be capturing the good luck that the countries in the sample have had.

The appropriate interpretation of the high estimated coefficient may be that equipment investment is necessary for rapid economic growth, but not sufficient. Investments in infrastructure, in other forms of non-residential and residential construction, and in human capital acquired through formal education are to some degree necessary complements to investments in machinery and equipment. Perhaps the high estimated coefficient should be interpreted as showing that such investments yield low returns unless private-sector entrepreneurs also make the decision to invest on a large scale in machinery. Investments in machinery and equipment would yield similar low returns unless supported by complementary investments in skills and infrastructure. Under this interpretation, the high coefficient on equipment and machinery investment arises because it is the least noisy signal of an interrelated complex of essential complementary growth factors, not because it is the most important of these growth factors.

Such an interpretation is somewhat strained. It is hard to see why machinery investment should be so much more accurately measured and so much better a signal of the growth-inducing complex of factors than education or other forms of investment unless machinery and equipment investment is in some sense *the* salient factor. Thus it is difficult to read the quantitative macro evidence as showing anything other than that equipment investment is the salient determinant of growth in the very long run growth record of industrialized countries.

B. Economic Growth and Industrial Policies

This suggests a line of thought that may be helpful in resolving an important debate within contemporary development economics. Over the past two decades, many have argued that the typical systems of government regulation introduced in developing countries to accelerate development were in fact retarding development. First, they were preventing the economy from responding to international price signals by shifting resources to activities in which the country had a long-run comparative advantage. Second, they were inducing firms and entrepreneurs to devote their energies to seeking rents by lobbying governments instead of seeking profits by lowering costs (Krueger 1974, Bates 1981, Lal 1985).

Critics of this line of thought have not been silent. They have pointed to countries—most notably Japan and Korea—that are by every definition prone to rent-seeking behavior, have explicitly eschewed *laissez-faire* development strategies, and yet have grown very rapidly (Johnson 1982, Westphal 1990). And they have argued that just because some cases of government regulation have been destructive does not mean that all will be, or that at the margin a shift to an activist “industrial policy” will be harmful.

Noting the salience of machinery investment as a determinant of very long run and post-World War II productivity growth points the way to a possible reconciliation. Countries like Japan and Korea have exhibited relatively low, not high, prices of machinery and equipment (and high quantities) in the post-World War II. This suggests that producers of capital goods have more often than not been on the losing side of rent-seeking coalitions in Japan and Korea. Perhaps high growth is consistent with a policy régime susceptible to rent-seeking as long as interests seeking high prices and low quantities of machinery investment are on the losing side of political contests.[29]

C. Conclusion

There is a strong association between machinery investment rates and long-run rates of productivity growth over the past century in a data base containing six large industrial nations. Each one percentage point increase in the machinery investment share of national product increases national product per capita growth by approximately 0.4 percentage points per year. This association is not the result of outlier nations or periods. A number of considerations suggest that machinery investment is in a sense *the* strategic factor in long-run productivity growth—a hypothesis also suggested by narrative accounts from the history of technology.

Almost 150 years ago, John Stuart Mill (1848) looked forward to the rapid erosion of the enormous edge in productivity that western Europe had gained over the rest of the world as a result of the industrial revolution. Mill's expectations have been disappointed. Even though some sizeable groups of countries have converged in productivity levels,[30] the divergence in productivity between the core industrial economies and the rest has if anything grown wider since his day. Measured in terms of relative material well-being, today the standards of living

---

[29]But note that rent-seeking behavior has presumably had a significant negative impact on consumer welfare in Japan and Korea, by depriving consumers of access to imports and by preserving agricultural sectors that consume much land and yield relatively little by world standards.

[30]The OECD is one such group. Western Europe is another. See Dowrick and Nguyen (1989), Baumol, Blackman, and Wolff (1990), or Abramovitz (1986).

attained appear to be more dependent on one’s country of birth than at any other time in human history.

In the past, those countries that have grown most rapidly are those that have invested very heavily in machinery, and in doing so acquired mastery of the technologies of the industrial revolution embodied in machinery. This is a vision of the process of economic growth that is very familiar to economic historians. And it may well be that economic historians have much to teach, and should be eager to teach, those trying to guide poorer nations of the world toward mastery of modern industrial technologies.

References

Abramovitz, Moses (1986), "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History* 46 (June), 385–406.

Abramovitz, Moses (1956), "Resource and Output Trends in the United States since 1870," *American Economic Review Papers and Proceedings* 46 (May), 5–23.

Bates, Robert (1981), *Markets and States in Tropical Africa: The Political Economy of Agricultural Policies* (Berkeley, CA: University of California Press).

Baumol, William; Beatty Blackmun, Sue Anne; and Wolf, Edward (1990), *Productivity and American Leadership: The Historical Record* (Cambridge, MA: M.I.T. Press).

Blanqui, Jérôme-Adolphe (1837), *Histoire de l'Economie Politique en Europe*, Eng. version trans. Emily Leonard from the fourth French ed. (New York: G.P. Putnam's Sons, 1880).

Chandler, Alfred (1978), *The Visible Hand* (Cambridge, MA: Harvard University Press).

Clark, Colin (1937), *National Income and Outlay* (London: Macmillan).

David, Paul (1990), personal communication.

David, Paul (1977), "Invention and Accumulation in America's Economic Growth: A Nineteenth Century Parable," in Brunner, Karl and Allan Meltzer, eds., *International Organization, National Policies, and Economic Development* (New York: North-Holland).

De Long, J. Bradford (1988), "Productivity Growth, Convergence, and Welfare: Comment," *American Economic Review* 78 (December), 1138–54.

De Long, J. Bradford, and Barry J. Eichengreen (1991), "The Marshall Plan: History's Most Successful Structural Adjustment Program," forthcoming in Rüdiger Dornbusch, Richard Layard, and Wilhelm Nölling, eds., *Post World War II Reconstruction: Lessons and Analogies.*

De Long, J. Bradford, and Marco Becht (1991), "'Excess Volatility' in the German Stock Market, 1876–1990" (Cambridge, MA: NBER).

De Long, J. Bradford and Lawrence H. Summers (1991), "Equipment Investment, Relative Price Structures, and Economic Growth," *Quarterly Journal of Economics*.

de Vries, Jan (1984), "The Decline and Rise of the Dutch Economy, 1675–1900," in Gary Saxonhouse and Gavin Wright, eds., *Technique, Spirit, and Form in the Making of the Modern Economies: Essays in Honor of William N. Parker*, published as supplement 3 to the journal *Research in Economic History*.

Denison, Edward (1967), *Why Growth Rates Differ: Postwar Experience in Nine Western Countries* (Washington, DC: The Brookings Institution).

Díaz-Alejandro, Carlos F. (1970), *Essays on the Economic History of the Argentine Republic* (New Haven, CN: Yale University Press).

Dowrick, Steven, and Tom Nguyen (1990), "OECD Comparative Catchup and Convergence," *American Economic Review* 80.

Feinstein, Charles (1972), *National Income, Expenditure, and Output in the United Kingdom* (Cambridge, U.K.: Cambridge University Press).

Firestone, O. J. (1953), *Canada's Economic Development, 1867–1952* (Ottawa, Canada: Department of Trade and Commerce).

Fishlow, Albert (1966), "Productivity and Technological Change in the Railroad Sector, 1840–1910," in Dorothy Brady, ed., *Output, Employment, and Productivity in the U.S. after 1800* (New York: National Bureau of Economic Research).

Fua, Giorgio, ed. (1969), *Lo Sviluppo Economico in Italia* (Milan: Angeli).

Gallman, Robert (1960), "Commodity Output, 1839–99," in William Parker, ed., *Trends in the American Economy in the Nineteenth Century* (Princeton, N.J.: Princeton University Press).

Gerschenkron, Alexander (1962), *Economic Backwardness in Historical Perspective* (Cambridge, MA: Harvard University Press).

Hawke, David F. (1990), *Nuts and Bolts of the Past* (New York: Harper and Row).

Hayn, Rolf (1962), "Capital Formation and Argentina's Price-Cost Structure, 1935–58," *Review of Economics and Statistics*

Hill, T.P. (1964), "Growth and Investment According to International Comparisons," *Economic Journal* (June).

Hoffman, W.G.; F. Grumbach, and H. Hesse (1965), *Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts* (Berlin: Springer).

Hounshell, David (1984), *From the American System to Mass Production: The Development of Manufacturing Technology in the United States* (Baltimore, Md.: Johns Hopkins University Press).

Hunter, Louis (1949), *Steamboats on the Western Rivers* (Cambridge, Mass.: Harvard University Press).

Johnson, Chalmers (1982), *MITI and the Japanese Miracle* (Palo Alto, CA: Stanford University Press).

Jones, Charles (1991), "Economic Growth and Producer Durables Prices" (Cambridge, MA: M.I.T. xerox).

Jorgenson, Dale (1990), "Productivity and Economic Growth" (Cambridge, MA: Harvard University xerox).

Kelley, Allen; and Williamson, Jeffrey (1971), "Writing History Backward: Meiji Japan Revisited," *Journal of Economic History* (December), pp. 729–76.

Kravis, Irving, Alan Heston, and Robert Summers (1982), *World Product and Income:*

International Comparisons of Real Gross Product (Baltimore, MD: Johns Hopkins University Press).

Krueger, Anne O. (1990), "Government Failures in Development," *Journal of Economic Perspectives* 4:3 (Summer), pp. 9–23.

Krueger, Anne O. (1974), "The Political Economy of the Rent Seeking Society," *American Economic Review* 64

Kuznets, Simon (1971), *The Economic Growth of Nations* (Cambridge, MA: Harvard University Press).

Kuznets, Simon (1962), *Capital in the American Economy: Its Formation and Financing* (Princeton, N.J.: Princeton University Press).

Lal, Deepak (1985), *The Poverty of 'Development Economics'* (Cambridge, MA: Harvard University Press).

Landes, David (1969), *The Unbound Prometheus* (Cambridge, U.K.: Cambridge University Press).

Lewis, W. Arthur (1978) *Growth and Fluctuations* (London: Allen & Unwin).

Maddison, Angus (1989), *Economic Growth in the Twentieth Century* (Paris: OECD).

Maddison, Angus (1982), *Phases of Capitalist Development* (Oxford, U.K.: Oxford University Press).

McLean, Ian (1990), "No Flash in the Pan: Economic Growth in Nineteenth-Century Resource-Rich Settler Economies" (Adelaide: University of Adelaide xerox).

McLean, Ian and Duc-Tho Nguyen (1989), "Growth, Investment, and Convergence 1870–1938" (Adelaide: University of Adelaide xerox).

Mill, John Stuart (1848), *Principles of Political Economy,* ed. by W.J. Ashley (London: Macmillan).

Milward, Alan (1984), *The Reconstruction of Western Europe, 1945–51* (Berkeley, CA: University of California Press).

Mokyr, Joel (1990), *The Lever of Riches* (Oxford, U.K.: Oxford University Press).

Mulhall, Michael (1896), *Industries and Wealth of Nations* (London: Longmans, Green, and Co.).

Ohkawa, Kazushi (1966), *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinpo Sha).

Patrick, Hugh, and Rosovsky, Henry (1976), *Asia's New Giant: How the Japanese Economy Works* (Washington, DC: The Brookings Institution).

Pollard, Sidney (1982), *Peaceful Conquest: The Industrialization of Europe 1760–1970* (Cambridge, UK: Cambridge University Press).

Porter, Michael (1990), *The Competitive Advantage of Nations* (New York: Free Press).

Rosenberg, Nathan (1982), *Inside the Black Box: Technology and Economics* (Cambridge, U.K.: Cambridge University Press).

Rosenberg, Nathan (1978), "Progresso Tecnico: L'Analisi Storica," in *Il Mondo Conemporaneo, vol. VIII: Economia E Storia—2,* pp. 626–45. Translated as "The Historiography of Technical Progress," in *Inside the Black Box,* pp. 3–32.

Rosenberg, Nathan (1976), *Perspectives on Technology* (Cambridge, U.K.: Cambridge University Press).

Rosenberg, Nathan (1972), *Technology and American Economic Growth* (New York: Harper and Row).

Rosenberg, Nathan (1963a), "Capital Goods, Technology, and Economic Growth," *Oxford Economic Papers* 15.

Rosenberg, Nathan (1963b), "Technological Change in the Machine Tool Industry, 1840–1910," *The Journal of Economic History* (December).

Rosovsky, Henry (1972), "What Are the 'Lessons' of Japanese Economic History," in A. Youngson, ed., *Economic Development in the Long Run* (New York: St. Martin's Press).

Rostow, Walt Whitman (1990), *Theories of Economic Growth from David Hume to the Present* (London: Oxford University Press).

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

Srinivasan, T.N. (1990), "Development Thought, Strategy, and Policy: Then and Now" (New Haven: Yale University).

Summers, Robert and Alan Heston (1991), "The Penn World Table, Version V," *Quarterly Journal of Economics* .

Summers, Robert, and Alan Heston (1984), "A New Set of International Comparisons of Real Product and Prices: Estimates for 130 Countries," *Review of Income and Wealth*.

Trajtenberg, Manuel (1990), *The Economic Analysis of Product Innovation: The Case of Computerized Tomography Scanners* (Cambridge, MA: Harvard University Press).

Usher, Abbott P., *The Industrial History of England* (Boston: Houghton-Mifflin, 1920).

van der Linde, Claas (1990), "The German Printing Press Industry" (Geneva: St. Gall School of Business).

Westphal, Larry (1990), "Industrial Policy in an Export-Propelled Economy: Lessons from South Korea's Experience," *Journal of Economic Perspectives* 4:3 (Summer), pp. 41–60.

Williamson, Jeffrey (1991), "The Evolution of Global Labor Markets in the First and Second World since 1830: Background Evidence and Hypotheses" (Cambridge, MA: Harvard

University xerox).

Wolf, Hans-Jürgen (1981), *Schwarze Kunst: Eine Illustreirte Geschichte der Druckverfahren* (Frankfurt: Deutscher Fachverlag).