Equipment Investment and Economic Growth: How Strong Is the Nexus?

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I. Introduction

A. Accounting for Growth

Productivity growth is *the* important dimension of long-run economic performance. A nation that sees productivity grow three percent per year sees income per worker rise eight fold over a lifetime; income only doubles if annual growth is one percent. Britain has gone from the world's industrial leader in 1870 to its current position by lagging the industrial annual growth average by 0.75 percent per year. Differences in growth cumulate to dwarf even the most serious post-WWII recessions.

Economists have said relatively little about how policies affect the transcendentally important long-run growth rate. Textbook theories of the type pioneered by Solow are set up so that policies cannot affect growth rates over a sufficiently long run. The growth-accounting tradition of Solow (1957) and Denison (1967) has tended to conclude that the largest part of differences in growth are not due to differences in measured investments, but to a "residual"—total factor productivity (TFP). Such models produce what Solow (1991) calls "investment pessimism": radical policy changes that have large effects on investment and other resource allocations have little effect on long-run growth.

Yet economies grow, and grow at different rates. If such differences in growth are due to resource allocation decisions that affect productivity, one cannot use private rewards to evaluate social returns. There is then little alternative to exploiting natural experiments provided by the very different economic policies, investment outcomes, and economic growth rates found in different nations.[1]

In De Long and Summers (1991), we focused on equipment investment as potentially a particularly key factor in growth. Using data from the U.N. International Comparison Project (hereafter ICP), we distinguished between "investment effort"—current consumption foregone—and actual investment in an economy: buildings constructed and machines put into operation. The real price of equipment differs by as much as a factor of four across countries, making nominal investment shares very imperfect measures of real investment. We found that countries with high equipment investment grew extremely rapidly even controlling for a large number of other factors. This association suggested a causal relationship: rapid growth went with high equipment investment no matter whether high

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[1]This is the approach taken in many recent empirical studies of growth in the "endogenous growth theory" tradition largely sparked by Paul Romer (1986). See Barro (1991), and the other papers published in the May 1991 *Quarterly Journal of Economics* (including our De Long and Summers (1991)), for a sample of such work.

equipment investment was a consequence of high savings or of a low relative equipment price.

This paper extends our earlier work in four important ways. First, we verify the growth-equipment nexus using new cross-country data to demonstrate that our strong results are not the result of Darwinian biases in specification selection. Second, we focus on the possibility that the growth-equipment nexus varies in strength with an economy's productivity level. We find little sign that the richest are different from others in this respect. Growth—measured by labor or by TFP—is as tied to high equipment investment for rich as for newly-industrializing nations.[2]

Third, we present further statistical evidence suggesting that variations in equipment investment arising from different sources have similar impacts on growth. We support our evidence with case studies linking differences in policies towards equipment to poor performance in Argentina and impressive performance in Japan over the past few decades. Fourth and last, we calculate social rates of return to investments in equipment. We find that equipment appears to have a very high *net* social return in the range of twenty percent per year. This suggests, significantly, large external benefits from equipment. We conclude that policies that tilt the playing field against equipment are likely to be disastrous, and there is a strong case for at least modest bias in favor of equipment.

II. The Robust Association of Equipment and Growth

A. Motivation

There are good reasons to believe *ex ante* that equipment investment might have a strong association with growth. The link between productive technologies and the capital goods in which they are embodied is a central component of economic histories.[3] Steam engines were necessary for steam power; textile manufacture required power looms and spinning machines; assembly line production was unthinkable without heavy investments in the high-precision machines that made interchangeable metal parts. New and improved technologies require new and improved types of capital. Technological change is capital using, and TFP cannot increase without an increase in capital intensity as well.[4]

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[2] And is in fact weaker among the poor. See Pritchett (1991), and De Long and Summers (in process).

[3] See Landes (1969) and Mokyr (1989).

[4] See Jorgenson (1991). Note, however, that it is very difficult to a large share of differences in national rates of productivity growth to "embodiment" effects in the strict sense. Embodiment in the strict sense affects productivity only as the average

A more important factor than embodiment or the factor-using bias of technological change may be the key role that students of industry and technology tell us is played by experience and feedback in gaining the ability to produce efficiently using new technologies. Trial-and-error and experience are the best ways to learn what works—and how what was previously built needs to be modified to be efficient. Historians of technology like Mowery and Rosenberg (1989) stress that much technological knowledge is "tacit": based on hands-on experience, hard to summarize, difficult to transmit through education. Such hands-on experience presupposes investments in the machines on which to learn.

The importance of trial-and-error and experience is magnified by the process of incremental adaptation needed to turn a new idea into an efficient production process. Experience is the best teacher not only for the user, but also for the manufacturer and the designer of capital goods. As Rosenberg (1976) puts it: "…most inventions are relatively…inefficient.…[They are] of necessity badly adapted to many of the ultimate uses to which they will eventually be put." Mowery and Rosenberg (1989) criticize those who regard "innovation…as…the application of 'upstream' scientific knowledge to the 'downstream' activities of new product design and…new manufacturing processes." In Mowery and Rosenberg's view "the primary sources of innovation [is]…'downstream'"; improved machines and better ways of using them do not emerge without users to pinpoint useful modifications.[5]

These qualitative patterns suggest that "learning by doing"[6] may be at the fore of productivity growth. In this case, the acquisition and use of equipment may be important for its "indirect" effects: what workers learn and what organizations learn about how to efficiently use modern technologies from the experience of installing and using capital. Workers gain valuable hands-on experience in handling sophisticated technologies. Organizations learn how to modify operating procedures. Such a view leads naturally to an expectation of high social returns from equipment investment, for equipment investment is a necessary precondition for this process of learning and experience to begin.

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age of the capital stock changes, and the average age of capital is relatively insensitive to shifts in the rate of investment. See Denison (1964).

[5]A similar stress on incremental improvement is found in studies of the adaptation of well-known technologies to factor intensities and resources in industrializing countries. Rosovsky's (1972) studies of Japan's industrial success lay stress on Japanese excellence in what Rosovsky terms "improvement engineering": "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." Such adaptation can consume important resources. Caves and Uekesa (1976) report a mid-1960s survey finding that one-third of Japanese R&D expenditures were devoted to modifying imported technology for use.

[6]See Arrow (1962).

Such a view also leads to the expectation that social returns are higher than private returns, for such "indirect" increases in productivity could be kept proprietary only with difficulty. Workers who can use and adapt technologies can and do demand higher wages, for their newly-acquired skills are valuable to firms down the street. Firms copy operating procedures from path-breaking competitors.

B. Previous Results

In De Long and Summers (1991), we regressed output per worker growth over 1960–85 (measured in 1985 international dollars) on estimates of the share of output devoted to investment in equipment over 1960–85. We used estimates of national relative price and quantity structures for benchmark years denominated in "international dollar" units from the United Nations ICP, which allows for cross-national comparisons orders of magnitude more accurate than those made before (see Kravis, Heston, and Summers, 1982). We used estimates of total investment devoted to equipment derived from benchmark-year data of Kravis, Heston, and Summers (1982) and other ICP observations to estimate the share of equipment investment in GDP over 1960–85. We then merged our equipment investment estimates with the cross-country comparative growth accounts of Summers and Heston (1988, 1991).[7]

Our basic regressions controlled for labor force growth, investment in non-equipment capital, and the productivity gap vis-a-vis the world's industrial leader. Most important, our study took care to distinguish investment from "investment effort." Different countries have radically different price structures. The same foregone consumption purchases three times as much machinery and equipment in post-WWII Japan as in post-WWII Argentina.

Figure 1 and table 1 present some of our earlier results for our full sample of 61 non oil-exporting nations, and for a high-productivity sample of 25 rich nations that had already progressed far toward industrialization. These high-productivity economies possessed the infrastructure to use modern technologies.

Determinants and patterns of growth among poorer economies are in all probability very different from those of advanced industrial economies. If we are concerned with the determinants of growth in industrial economies, there is good reason to pay more attention to the high-productivity than to the

[7] Note that these estimates depend on the ratio of equipment to total investment in benchmark years being a good proxy for the average ratio of equipment to total investment, and are confined to economies that served as benchmarks in the ICP.

full sample. But there is a very strong association between equipment investment and growth for regressions that include a variety of additional controls, and in both samples. Moreover, there is no sign that the very richest economies—in northwest Europe, North America, and Australia—are outliers following different laws of motion than the rest of the high-productivity sample.

Figure 1
Partial Scatter of Growth and Equipment Investment: Previous Evidence

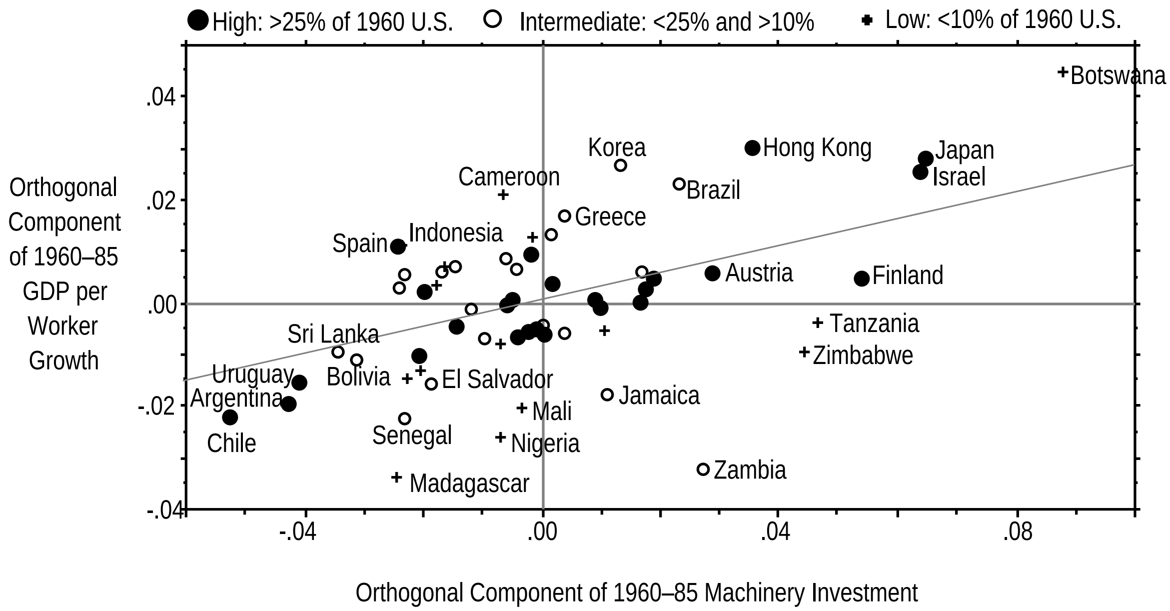


Figure 1 plots the partial scatter of equipment investment and GDP per worker growth. Its vertical axis measures that component of 1960–1985 GDP per worker growth orthogonal to the three control variables in the regression shown in the first column of table 1. Its horizontal axis measures the component of the 1960–85 equipment investment orthogonal to the same controls. The figure shows point-by-point the partial correlation of equipment investment and GDP per worker growth in our earlier sample. Table 1 reports regression results.[8]

Table 1
Basic Regression Results from De Long and Summers (1991)

Independent Variables	High-Productivity 1960–85	High-Productivity 1960–75	High-Productivity 1975–85	Incl. Devel. Economies 1960–85	Schooling Variables Incl. Devel.	Continent Dummies Incl. Devel.
Equipment Investment Share of GDP	0.337 (0.054)	0.295 (0.075)	0.425 (0.105)	0.265 (0.065)	0.275 (0.070)	0.288 (0.072)

[8]ncluded in table 1 are regressions adding to our basic independent variables among the independent variables five politico-economic variables which Barro (1991) stresses as likely to have substantial influence on growth rates—the annual rates of political assassinations and coups over 1960–85, 1960 primary and secondary school enrollment rates, and the average 1960–85 share of government consumption expenditures in GDP—regressions adding continent dummies, and regressions covering subperiods of the 1960–85 period.

Non-Equipment Investment Share of GDP	-0.015 (0.033)	-0.056 (0.043)	0.047 (0.059)	0.062 (0.035)	0.029 (0.037)	0.022 (0.038)
Labor Force Growth	-0.002 (0.146)	-0.081 (0.197)	-0.177 (0.258)	0.031 (0.198)	-0.001 (0.203)	0.143 (0.285)
GDP per Worker Gap vis-a-vis the U.S.	0.030 (0.009)	0.049 (0.013)	0.014 (0.016)	0.029 (0.009)	0.039 (0.013)	0.029 (0.012)
R^2	0.662	0.593	0.428	0.291	0.391	0.385
SEE	(0.008)	(0.009)	(0.013)	(0.013)	(0.012)	(0.012)
n	25	25	25	61	61	61

An increase of three or four percentage points in the share of GDP devoted to equipment investment is associated with an increase in GDP per worker growth of 1 percent per year. Differences in equipment investment account in a statistical sense for much of the growth performance of fast- or slow-growing nations. Japan achieved a growth rate edge of 2.2 percent per year over 1960–1985 relative to the average pattern in the sample. Conversely, Argentina has suffered a growth rate deficit of 2.1 percent per year. More than four-fifths of this difference is accounted for in table 1 by high or low equipment investment.

C. New Sample Periods

1. The 1950s

The comparative performance of economies in the 1950s provides a source of information on the strength of the growth-equipment investment nexus which we did not previously tap in De Long and Summers (1991). We have constructed estimates of equipment investment rates in the 1950s for 54 economies.[9] Figure 2 plots the partial scatter of growth and equipment investment in the 1950s for the high-productivity nations in our 1950s sample, and table 2 presents regression results. Because of the

[9] As in De Long and Summers (1991), we omit high-income oil-exporting nations from our sample. For OECD nations and some others for which detailed year-by-year measures of the components of investment are also available, estimates of equipment investment in the 1950s are derived from official OECD (or UN) estimates of the current-price equipment investment share, adjusted to the Summers-Heston international dollar price vector. For other economies, estimates of equipment investment in the 1950s have been constructed by multiplying the Summers and Heston (1991) estimates of total investment shares in the 1950s by our own estimates of the 1960–85 equipment share of total investment from De Long and Summers (1991). The non-OECD data are therefore of relatively low quality: they contain no new information about the division of investment between machinery and structures. The OECD data especially, however, are almost as good for the 1950s as for the 1960–85 period: they do contain substantial amounts of information about the division of investment between categories. In the regressions in this paper our equipment investment variable includes investment in producer transportation equipment, a subcategory omitted from the equipment category of our previous paper. We also use the log of the productivity gap vis-a-vis the U.S. rather than the level of the productivity gap as an independent variable. The log gap has a much more natural interpretation.

short period of the sample, standard errors are relatively large. But coefficient magnitudes are almost the same. The experience of the 1950s is not a duplicate of the experience of 1960–85. In the 1950s Germany, especially, is an extra high growth-high equipment country, and Brazil—moderate investment-high growth over 1960–85—is a high investment-moderate growth country in the 1950s. The 1950s are a different natural experiment than 1960–85.

Figure 2
Partial Scatter of Growth and Equipment Investment in the 1950s

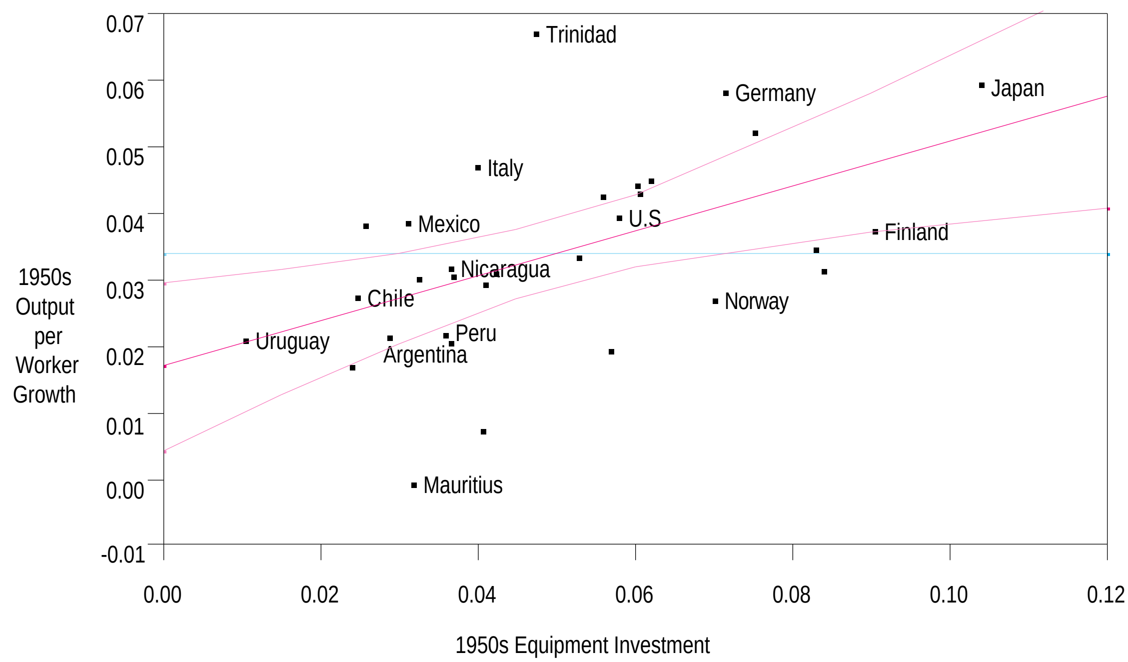


Table 2 shows, as did table 1, that the inclusion of some additional growth-related factors does not have large effects on the estimated equipment coefficient. The equipment-growth association is not due to the omission of easily-measured education proxies, or of fixed continent-specific factors. It also shows, once again, no significant differences between high-productivity economies and the sample as a whole.

Table 2
Growth Regressions for the 1950s

	High-Pdty[11] Economies	with[10] Schooling Variables	with Continent Dummies	All Economies
Equipment Investment	0.343	0.372	0.187	0.275
	(0.112)	(0.158)	(0.123)	(0.108)

[10]Primary and secondary enrollment rates as a fraction of the school-age population in 1960.
[11]Economies with 1950 or 1960 output per worker levels at least one-fifth that of the United States.

Non-Equipment Investment	0.016	-0.005	-0.010	0.043
	(0.055)	(0.062)	(0.056)	(0.050)
Log Pdty Gap vis-a-vis US[12]	0.021	0.023	0.020	0.007
	(0.006)	(0.006)	(0.007)	(0.003)
Labor Force Growth	--0.042	0.019	0.359	-0.372
	(0.236)	(0.272)	(0.333)	(0.222)
Primary School Enrollment			0.021	
			(0.017)	
Secondary School Enrollment			-0.010	
			(0.021)	
R^2	0.289	0.475	0.506	0.686
SEE	0.0159	0.0137	0.0138	0.0118
n	54	31	31	31

2. The 1980s

Few years have elapsed since the 1985 end of our previous sample. As Easterly *et al.* (1992) have pointed out, there is substantial year-to-year variation in cross-country growth rates The variance explainable in a cross-country regression over five years is smaller than the share explainable over a longer era. Because of this high short-run variance, coefficients will be poorly estimated. Nevertheless, figure 3 and table 3 report regressions for the short 1985–90 period. Table 3 shows that in this case we have pushed beyond the limits the data can address.[13]

Figure 3
Partial Scatter of Growth and Equipment Investment 1985–90

[12] The log productivity gap is included rather than the productivity gap because the coefficient on the gap in log productivity has a much more straightforward interpretation: a coefficient of .02 means that two percent of the log productivity gap is closed with each year, or that .02 x 25 = fifty percent of the gap is closed over a twenty-five year period.

[13] For OECD nations the estimates of investment are derived from official OECD year-to-year estimates of national product, adjusted to the 1985 ICP. For other nations the share of equipment in investment was set equal to the ratio in the 1985 benchmark year. Thus for non-OECD nations the equipment investment rates over 1985–90 period are of low quality.

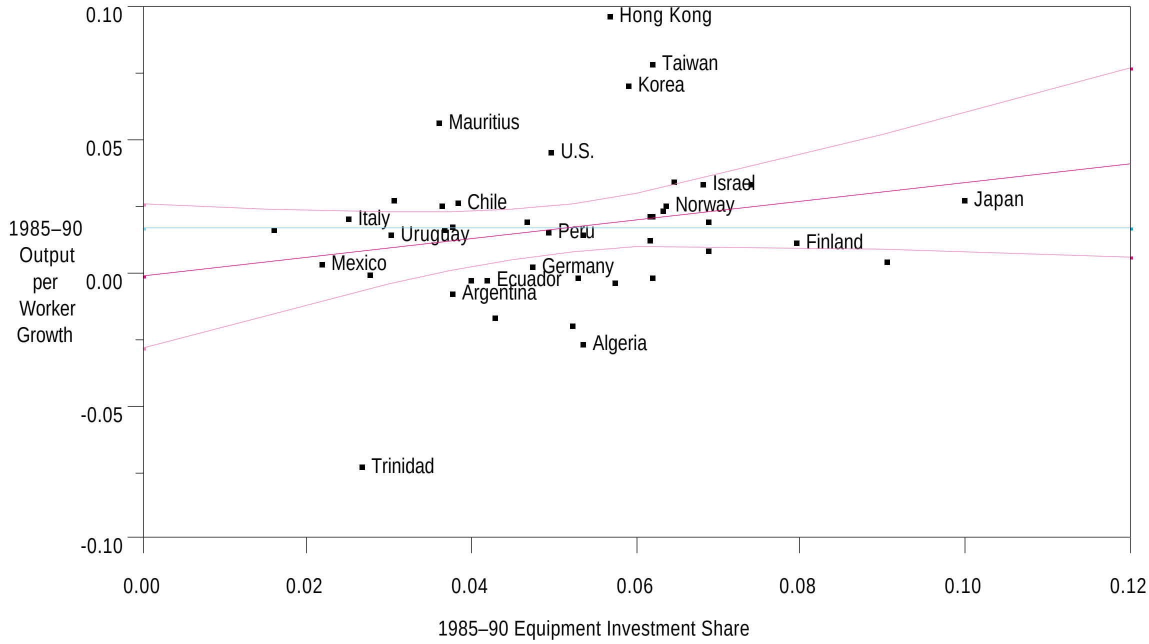


Table 3
Growth Regressions for the 1985–90 Period

	High-Pdty[14] Economies	Continent Dummies	Schooling Variables	All Economies
Equipment Investment	0.355	0.088	0.331	0.217
	(0.246)	(0.262)	(0.260)	(0.184)
Non-Equipment Investment	0.064	0.073	0.063	0.115
	(0.109)	(0.106)	(0.104)	(0.075)
Log Pdty Gap vis-a-vis US	0.050	0.038	0.052	0.007
	(0.016)	(0.018)	(0.019)	(0.005)
Labor Force Growth	--2.221	-3.119	-2.153	-1.176
	(0.529)	(0.717)	(0.557)	(0.406)
R^2	0.377	0.510	0.382	0.248
SEE	0.0290	0.0277	0.0297	0.0290
n	42	42	42	71

For the high-productivity sample the equipment coefficient is large—0.355. But it is imprecisely estimated. The residual variance of 1985–90 growth rates is very large, with a standard deviation of 2.8 percent per year. It is still worth noting the similarity of point estimates. By and large the relationship between growth and equipment that held in the 1950s and during 1960–85 continued to hold during 1985–90. The relationships estimated over 1960–85 data do well at forecasting growth over 1985–90.

[14]Economies with 1985 output per worker levels at least one-fifth that of the United States.

3. The Very Long Run

Equipment investment and growth are closely associated not just in the post-WWII period but in the longer-run as well. Here we analyze a long-run panel of seven nations (Canada, Germany, Italy, Japan, the United Kingdom, the United States, and Argentina) over 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 1980) of roughly fifteen years, with some dates offset to match business cycles and major wars.[15]

Figure 4 shows the partial scatter of equipment investment and output per worker growth. Each data point represents the experience of a nation in one period. Table 4 reports regressions for this long-run panel. The coefficient on equipment is in the same range as in the regressions above, and accounts for nearly a quarter of the variation in output per worker growth. Table 4 reports that introducing educational variables has no effect on the equipment coefficient.[16] Era dummies reduce, and nation dummies raise the coefficient by one standard error.[17] Thus no powerful nation- or era-specific effects appear in this panel.

Figure 4
Partial Scatter of Equipment Investment and Growth for the Very Long Run Panel

[15]This frequency of observation was chosen because we wished to focus on long-run shifts in growth rates produced by shifts in the production potential of economies, and not on short-run cyclical fluctuations produced by shifts in the relative rate of employment of resources. The data and specifications used here are modified versions of those used in De Long (1992). De Long (1992) showed a close association between output per capita growth and a “net concept” of equipment investment—the change in the gross machinery stock—over 1870–1980. Here we modify the specification to make it directly comparable with the gross investment regressions of other sections, and show that such a close association holds for the very long-run panel between output per worker growth and *gross* equipment investment.

[16]The educational enrollment variables have little partial association with growth. This does not imply that human capital accumulation is unimportant for growth, but only that estimates of enrollment rates are bad measures of human capital accumulation.

[17]Only one of the era dummy variables—that for 1929–38—is significantly different from zero. Only two of the nation dummy variables—Argentina and Japan— are significant, with Argentina low and Japan high.

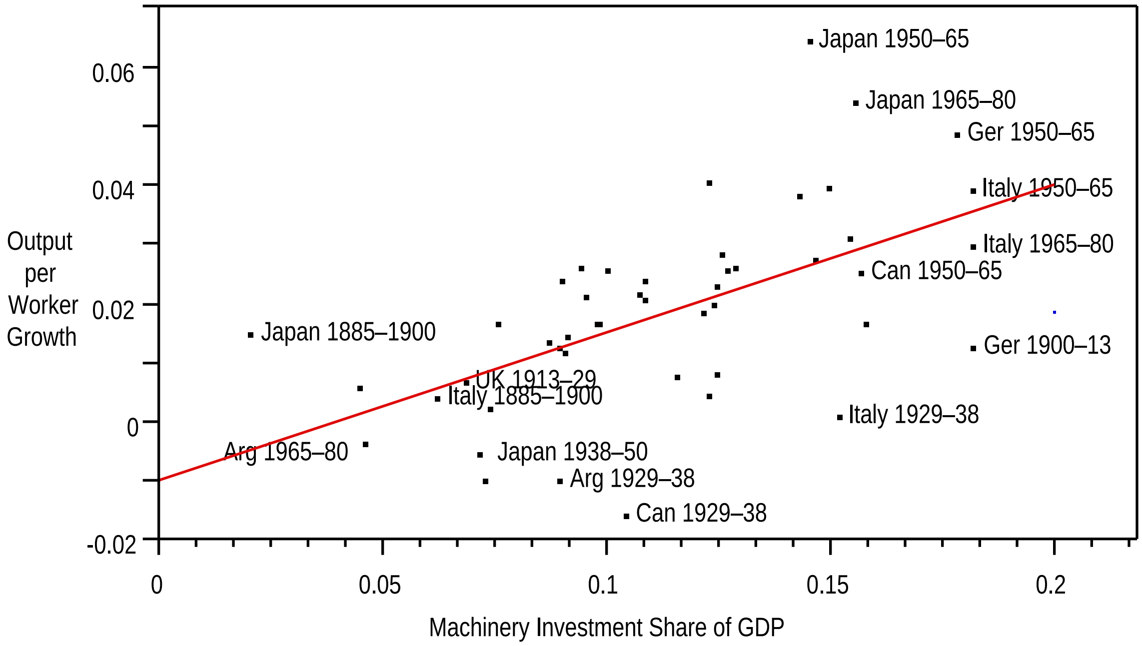


Table 4

Growth Regressions for the Very Long Run Panel

Independent Variables	Basic Specification	Education Variables	Era Controls	Nation Controls	Both Era and Nation Controls
Equipment Investment	0.249	0.241	0.195	0.329	0.286
	(0.055)	(0.066)	(0.058)	(0.061)	(0.083)
Non-Equipment Investment	0.009	0.012	-0.033	0.094	0.060
	(0.044)	(0.045)	(0.045)	(0.048)	0.053
Pdty Gap vis-a-vis US	0.017	0.014	0.020	0.021	0.029
	(0.008)	(0.010)	(0.008)	(0.019)	(0.022)
Labor Force Growth	0.449	0.960	0.514	0.683	0.719
	(0.426)	(0.518)	(0.426)	(0.421)	(0.511)
Primary Enrollment/	-0.014				
Population		(0.009)			
Secondary Enrollment/		0.004			
Population		(0.002)			
WWII Loser?	-0.038	-0.041	-0.050	-0.035	-0.049
	(0.009)	(0.009)	(0.010)	(0.008)	(0.010)
Nation Controls?	No	No	No	Yes	Yes
Era Controls?	No	No	Yes	No	Yes
R^2	0.531	0.623	0.666	0.723	0.804
SEE	0.0142	0.0142	0.0132	0.0124	0.0111
n	48	41	48	48	48

D. Additional Observations

The procedures used in De Long and Summers (1991) restricted our sample to those economies that had served as ICP benchmarks. Here we use alternative procedures for estimating real rates of equipment investment that allow us to construct estimates for economies not included in the ICP benchmark studies. Trade statistics are one fruitful source of data on machinery investment.[18] The relative price of machinery and equipment is another variable that has a high correlation with the rate of equipment investment.[19] We use Aitken's (1991) estimates of the relative price of machinery and equipment in the 1980s and Lee's (1992) estimates of real imports from the OECD over 1960–85 to impute equipment investment in 27 economies not in our 1991 sample.[20] Table 5 reports results using only these additional economies.

Even though the sample is small, the equipment coefficient remains high. Equipment investment is strongly associated with output per worker growth. Equipment investment by itself accounts for a large share of growth rate variation. And equipment investment has a much larger association with growth than other forms of investment. It is little affected by the inclusion of continent dummies, or of the political and educational variables of Barro's (1991) basic specification. Figure 5 shows the partial scatter, showing that this sample contains one extreme observation: Singapore. But the high equipment coefficient is not due to its inclusion.

Table 5
Equiment Investment and Growth Over 1960–85 for Additional Economies

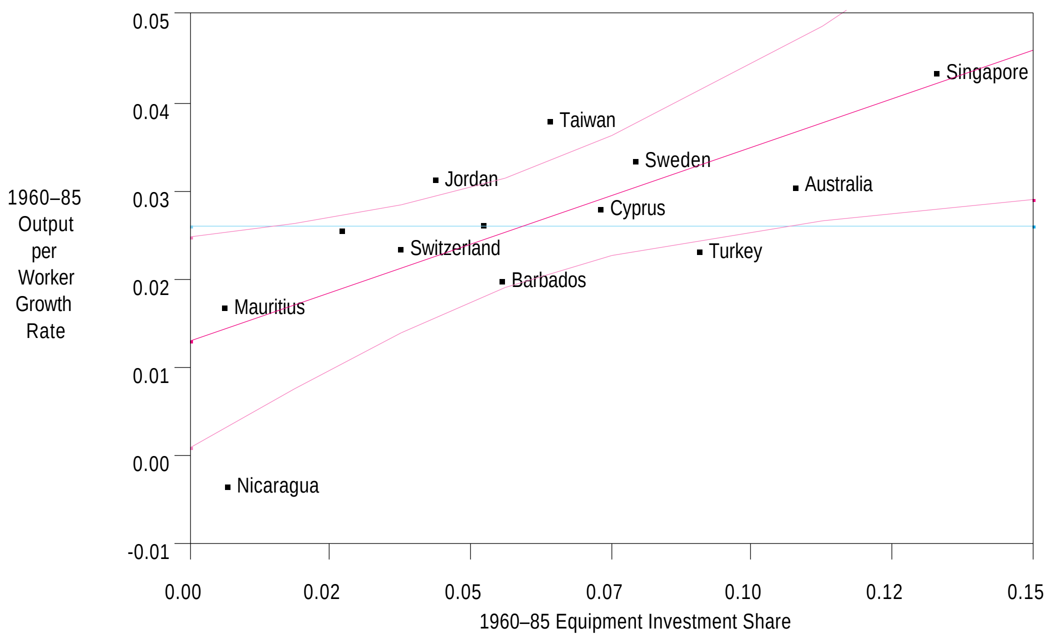
Independent Variables	High-Pdty[21] Sample	Schooling Variables	Including Continent Dummies	Including Politico-Econ. Variables	Including All Economies

[18]As Warner (1991) has shown, the bulk of equipment is imported from abroad in all except the very richest economies.
[19]As we showed in De Long and Summers (1991).
[20]In our 1991 sample, these proxies for equipment investment account for three quarters of the variation in equipment investment in our sample of ICP benchmark countries. The best predictor is the share of machinery imports in GDP: it is a direct output proxy, while the other proxy variables turn out to be more estimates of investment effort than of outcomes.

The most extreme outlier of the economies covered by ICP benchmarks is Brazil, which has a regression residual more than twice as large as any other when ICP estimates of equipment investment are regressed on imports and relative prices. According to Lee (1992), Brazil imported only 0.8 percent of GDP in equipment investment on average over 1960–85. Yet the ICP benchmark estimates of Brazil's equipment share of investment and Brazil's high general investment share of GDP led us to estimate in De Long and Summers (1991) that Brazil achieved a relatively high average rate of machinery investment: 4.1 percent of GDP over 1960–85. We believe that this large residual is a consequence of the import-substitution development strategy that Brazil chose to follow over this particular part of the post-World War II period. Brazil has eschewed imports of machinery and equipment, and has to a large degree attempted to build its own capital goods producing industries from scratch. It has achieved a surprising degree of success.
[21]Output per worker levels greater than twenty percent of the U.S. level in 1960 or 1985.

Equipment Investment	0.220	0.181	0.096	0.233	0.336
	(0.074)	(0.102)	(0.070)	(0.084)	(0.117)
Non-Equipment Investment	0.086	0.092	0.116	0.072	0.082
	(0.069)	(0.081)	(0.054)	(0.077)	(0.065)
Log Pdty Gap vis-a-vis US	0.021	0.022	0.016	0.028	0.006
	(0.005)	(0.006)	(0.004)	(0.009)	(0.005)
Labor Force Growth	-0.187	-0.046	0.871	-0.441	-0.122
	(0.451)	(0.594)	(0.467)	(0.550)	(0.442)
R^2	0.737	0.757	0.964	0.840	0.434
SEE	0.010	0.0107	0.0059	0.0095	0.0146
n	13	13	13	13	27

Figure 5
Partial Scatter of Growth and Machinery for Additional High-Productivity Economies



E. Maximal Cross-Section

Regressions combining all of the sources of data on equipment investment for the maximal cross-section sample over 1960–85 are shown in table 6, and figure 6.[22] As before, table 6 reports regressions

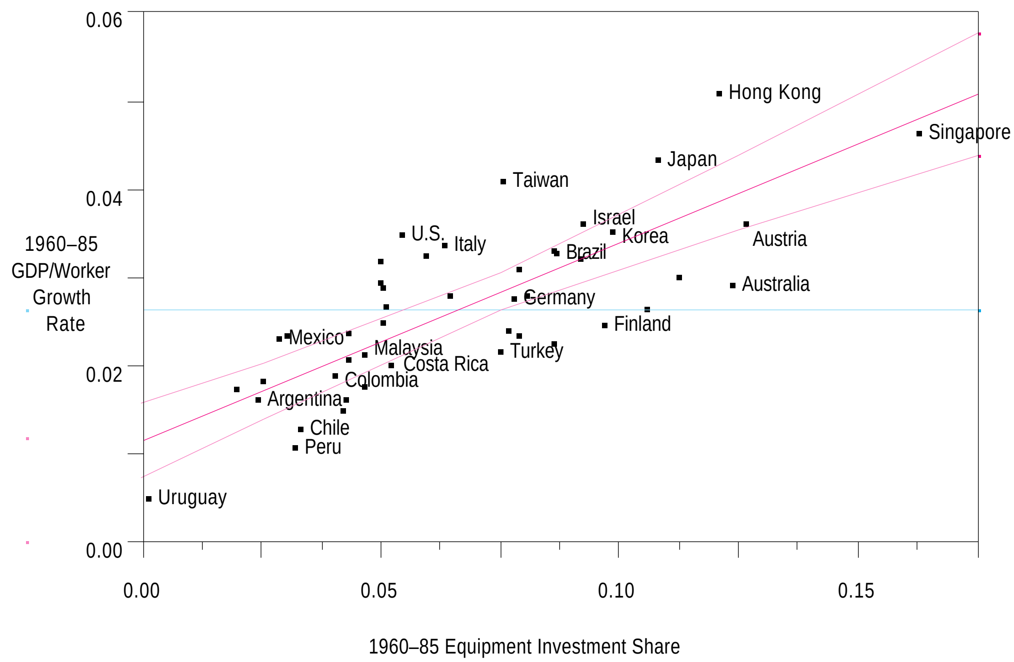
[22]Estimates of economic growth rates are taken from Summers and Heston (1991). Estimates of equipment investment rates are taken from the year-by-year breakdowns of real investment into equipment and other investment at Summers-Heston “international prices” for those economies for the forty-three economies for which such a breakdown exists. For other economies, the equipment share used is either the share imputed from imports of capital goods from the OECD, or an average of the equipment share estimate imputed from imports and the estimate made in De Long and Summers (1991).

a sample composed only of economies that had 1960 or 1985 GDP per worker levels at least one-fifth that of the United States, as well as some using the full sample. The results in figure 6 and table 6 are consistent with, and somewhat stronger than those estimated by De Long and Summers (1991). For the high-productivity sample the regression accounts for three-quarters of the variation in output, half again as much as in the corresponding regression in our 1991 paper. Figure 6 shows, once again, that the very highest productivity economies do not have consistently positive or negative residuals: Japan, Italy, and the U.S. are above while Austria, Australia, and Germany are below the fited regression line.

Table 6
Machinery Investment and Growth Over 1960–85 for the Maximum Cross Section

	High-Productivity Sample				All Economies
Indep.Variables	Basic Variables	Schooling Variables	Continent Dummies	Political Variables	Basic Variables
Equip.Investment	0.225 (0.030)	0.192 (0.036)	0.175 (0.038)	0.182 (0.035)	0.327 (0.050)
Non-Equip. Investment	0.077 (0.024)	0.077 (0.024)	0.060 (0.023)	0.076 (0.024)	0.062 (0.165)
Pdty Gap vis-a-vis US	0.018 (0.002)	0.020 (0.002)	0.015 (0.002)	0.022 (0.003)	0.007 (0.002)
Labor Force Growth	-0.013 (0.111)	0.073 (0.122)	-0.003 (0.136)	0.143 (0.128)	0.070 (0.166)
R^2	0.759	0.778	0.842	0.811	0.425
SEE	0.0068	0.0067	0.0059	0.064	0.0128
n	47	47	47	47	88

Figure 6
Partial Scatter of 1960–85 Growth and Machinery Investment for the Maximum Extended Cross Section, High-Productivity Sample



F. Sample Stratification

For the full sample, including the poorer developing nations, the maximal 1960-85 cross-section regression accounts for not three-quarters but only two-fifths of the variation in output per worker growth. The residual variance is four times as large as for the high-productivity sample. Many observations, especially sub-Saharan African nations with semi-socialized economies like Angola, Madagascar, Mozambique, Zaire, and Zambia, show extreme residuals. In samples that include the poorer developing economies, equipment investment and the other three basic variables are far from providing us with a comprehensive explanation of growth: significant dimensions of variation remain unaccounted for. This pattern—a significantly tighter fit and higher R^2 when the poorer developing economies are omitted from the sample— suggests a structural break in at least the magnitude of other, residual influences between the poorer and the non-poor economies. This is perhaps due to the poorer quality of the data for developing economies, but more likely due to the existence of other important omitted factors driving fast or slow growth.

Within the high productivity sample there is considerable heterogeneity as well. The sample includes newly industrializing economies like Taiwan, economies like Argentina that have seen a prolonged period of relative decline, and peripheral European economies like Portugal that are rapidly integrating themselves into western Europe as well as the advanced industrial economies of the world's economic core. As far as implications for U.S., or for G-7 economic policy are concerned, the finding of a close association between high equipment and rapid growth is considerably less interesting if it is driven solely by the experience of newly industrializing economies. It might be that economies with relatively low productivity can gain substantially from high equipment investment, but that richer economies that are already near the forefront of the world's best practice production processes do not.

Table 7
Machinery Investment and Growth Over 1960–85: Different Stratifications of the High-Productivity Sample

Cutoff Output/Worker Level	0.60	0.50	0.40	0.30
Equip.Investment (Above Cutoff)	0.230	0.212	0.223	0.229
	(0.039)	(0.034)	(0.029)	(0.030)
Equip. Investment (Below Cutoff)	0.222	0.243	0.146	0.160
	(0.032)	(0.038)	(0.059)	(0.062)
Non-Equip. Investment	0.077	0.079	0.079	0.075
	(0.024)	(0.024)	(0.023)	(0.024)
Pdty Gap vis-a-vis US	0.018	0.016	0.020	0.020
	(0.003)	(0.003)	(0.003)	(0.003)
Labor Force Growth	-0.001	-0.019	-0.038	0.018
	(0.109)	(0.111)	(0.109)	(0.109)
R^2	0.761	0.765	0.774	0.768
SEE	0.0068	0.0068	0.0067	0.0067
n	47	47	47	47

To investigate this possibility, we stratified the high-productivity 1960-85 sample by initial output per worker level relative to the U.S., imposing the restriction that coefficients on other variables be the same in the two pieces of the sample,[23] and estimates separate equipment coefficients for the richest economies (those above the output per worker cutoff chosen) and for the remaining, middle-income economies (those below the cutoff chosen). Table 7 reports results for four different stratification levels: thirty, forty, fifty, and sixty percent of U.S. output per worker. In no case is there a statistically significant difference between the equipment investment coefficients estimated for the two stratified pieces of the sample. There is very weak evidence for the cutoffs of thirty and forty percent that the

[23]Allowing other coefficients in addition to the equipment coefficient to vary in the two pieces of the high-productivity sample generates results that are fragile and inconclusive. There is insufficient identifying variance in the different pieces of the sample to generate precise estimates of all the regression coefficients. In a similar fashion, the interaction of output per worker and equipment using the high-productivity sample is of unstable sign.

growth-equipment nexus is weaker for middle-income than for the richest economies, but the associated t-statistic is less than 1.5. There is no strong reason to think that equipment investment matters much more, or less, for middle-income newly industrializing than for high income industrialized economies.

Our division of investment into equipment and non-equipment components is not the only breakdown. There is good reason to believe that other types of investment, such as research and development, and perhaps infrastructure, carry high social returns. Our exploratory regressions have not turned up evidence that would suggest a correlation between growth and public investment in infrastructure of the order of magnitude of the equipment investment-growth correlation documented above.[24] They have also failed to turn up evidence that, controlling for the mix of equipment and other capital, business investment has a stronger association with growth than residential construction.

To the extent that our data are able to distinguish among different breakdowns of investment into its components, the equipment component does have a uniquely strong association with growth. But attempting to distinguish between different potential breakdowns of investment carries us to, or perhaps beyond, the power of our macroeconomic dataset to discriminate among possibilities.

All samples and periods we have surveyed carry the same message. Regressions using new data, whether covering new periods or additional economies, strongly confirm our previous finding that the growth-machinery nexus is strong. The very long run panel data set, the cross-section regression covering the 1950s, the results for the 1985–89 period, the very long run panel, and the regressions run on additional economies. We have not found any strong differences in the strength of the growth-equipment relationship in samples stratified by productivity level.[25] We have not found other breakdowns of investment into components that do equally well at accounting for differences in growth rates. If a strong growth-equipment association is not a robust “stylized fact” but instead a product of some specific peculiarity or feature of our previous data, these tests of our specifications on new data should have revealed their fragility. They did not do so.

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[24]We have also failed to find any cross-sectional correlation between R&D investment and growth, once we control for equipment investment. But we attribute this to the paucity of data on R&D expenditures across countries.

[25]Although there is a large difference in the fraction of growth rate variation accounted for. Our regressions account for a smaller share of variation in samples that include poorer economies.

III. Equipment Investment and Total Factor Productivity Growth

A. Estimating Total Factor Productivity

It should come as no surprise that the very strong association of output per worker growth and equipment investment documented above is, in large part, also a strong association between equipment investment and total factor productivity growth. Given the limitations of our database, the calculation of total factor productivity estimates is not straightforward. We require estimates of the average share accruing to factors of production, and estimates not of gross but instead net investment rates. Thus total factor productivity estimates require estimates of initial capital stocks. Since such initial capital stock estimates are crude, they introduce a potential source of noise into TFP growth calculations.

We have estimated 1960-85 TFP growth rates for thirty-one of the economies in our high-productivity sample. For these thirty-one economies we have year-by-year estimates of nominal investment in different types of assets and of price structures in the 1950s. Along with an assumption about pre-1950 investment, we can construct 1960 estimates of capital stocks that can then be used to calculate total factor productivity growth over 1960–85. The restriction of our total factor productivity growth estimates to thirty-one high-productivity economies imposes on us a sample that does not show the growth-equipment nexus as strongly as some of our other samples. The equipment investment coefficient over the 1960–85 period is 0.198, toward the low end of the range found in our regressions

We assume that countries not World War II battlefields had achieved steady-state capital output ratios corresponding to their 1950s investment rates by 1960. For countries that were World War II battlefields, we assume that 1950 capital stocks were two-thirds of steady-state values. In estimating capital-output ratios, we assume depreciation rates of fifteen percent per year for equipment, and two percent per year for structures.

We also assume that the labor force in efficiency units is augmented by education. We set the effective labor force to the labor force multiplied by $(1+g)^S$, where g is a return on schooling, and S is the average schooling of the population from Barro and Lee (1992). We take the production function to be Cobb-Douglas in effective labor and in two types of capital, equipment and structures.

B. Total Factor Productivity and Equipment Investment

Table 8 shows results from our regressions of total factor productivity growth over 1960–85 on our basic variables, and on the change in schooling according to Barro and Lee (1992). The first three columns give parameters of the production function: α and β are the shares of output received by equipment and structures capital, and g is the assumed rate of return on education.

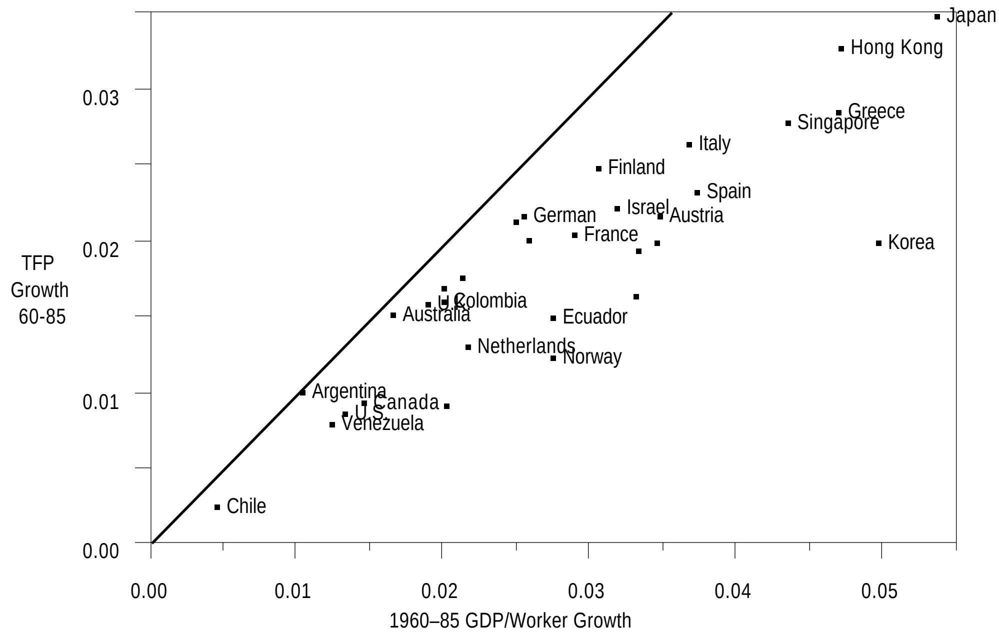
Table 8
Total Factor Productivity Growth Regressions

α	β	g	$r^{eq}+d^{eq}$	$r^{st}+d^{st}$	Equipment Investment	Other Investment	Labor Force Growth	Log Productivity Gap	Change in Achieved Schooling	R^2	SEE
.04	.20.10	0.22	0.13	0.130	0.052 (0.030)	-0.072 (0.027)	0.007 (0.097)	-0.0020 (0.002)	0.658 (0.0009)	0.0049	
.06	.20.20	0.34	0.13	0.125	0.051 (0.029)	-0.056 (0.027)	0.006 (0.095)	-0.0050 (0.002)	0.735 (0.0009)	0.0048	
.06	.20.10	0.34	0.13	0.125	0.051 (0.029)	-0.066 (0.027)	0.006 (0.096)	-0.0020 (0.002)	0.642 (0.0009)	0.0049	
.06	.30.10	0.34	0.19	0.098	0.045 (0.026)	-0.071 (0.024)	0.003 (0.084)	-0.0021 (0.002)	0.587 (0.0008)	0.0043	
.15	.30.10	0.87	0.19	0.072	0.041 (0.025)	-0.047 (0.023)	-0.000 (0.082)	-0.0020 (0.000)	0.503 (0.0009)	0.0042	

Figure 7 shows the difference between the estimates of total factor productivity growth and output per worker growth over 1960–85 for the second line in table 8. TFP growth and output per worker growth are correlated but far from collinear. The most extreme divergences between output per worker and total factor productivity growth come in the cases of Norway and Korea.[26] These economies aside, the rest appear grouped together in figure 7 near a line with a slope less than one: on average, those economies that have the largest gaps between TFP growth and output per worker growth (and thus the fastest rates of capital deepening) are also those economies that have the fastest TFP growth.

Figure 7
Scatter of TFP Growth and Output per Worker Growth

[26]Korean War destruction coupled with economic stagnation and low investment in the 1950s gave Korea very low capital-output ratios in 1960. Much of its rapid subsequent growth can be traced to making up the gap and realizing the very high private returns that standard models say should be present after such a decade of war destruction and low investment. Norway sees its capital significantly boosted toward the end of the sample as a result of the discovery of North Sea oil.

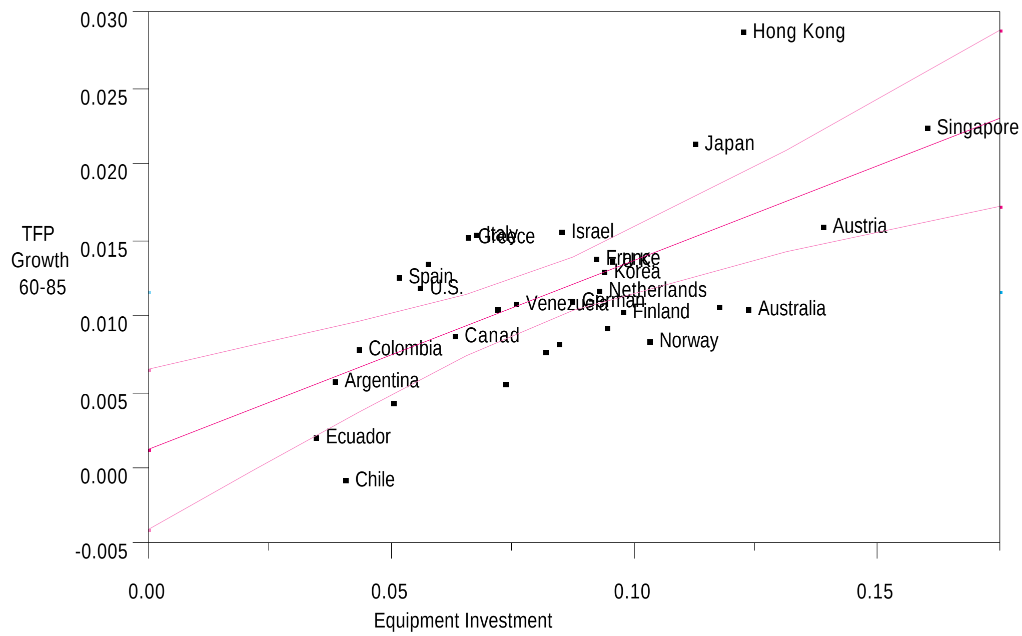


The fourth and fifth columns of table 8 give the mean *gross* private rates of return to investments in equipment and in structures in 1960, given the then-current capital-output ratios and the assumed production function parameters. The remaining columns present regression coefficients and summary statistics. Figure 8 plots the partial scatter of TFP growth and equipment investment for the regression in the second line of table 8.

The factor shares assumed in the first line of table 8 match economists' standard beliefs about rates of return most closely.[27] The other, subsequent lines are included primarily to demonstrate that allowing for higher private returns to investment does not remove the correlation between equipment investment and TFP growth. Line 1 allows for *net* private returns to investments in physical capital and in schooling in the range of seven to ten percent per year. The gross return to equipment is higher because the vaue flow of capital services from equipment must be higher than the flow from structures to offset equipment's higher depreciation rate.

Figure 8
Partial Scatter of TFP Growth and Equipment Investment, α = .06 β = .2 γ = .2

[27]Julio Rotemberg has observed that these estimated capital shares, while reasonable for OECD nations, are low for NIC economies. We have experimented with making capital shares a function of productivity levels, allowing for higher capital shares in poorer economies, and found no significant difference in our results.



All of the parameter values in table 8 produce high average private gross rates of return to investments in machinery and equipment. Yet even assuming such high private gross returns, there remains a significant association between equipment investment and growth: each percentage point of machinery and equipment investment boosts TFP by 0.13 percentage points when we assume an equipment capital share consistent with an average gross return to equipment investment in 1960 of twenty-two percent, by 0.12 percentage points when we assume an average 1960 return of thirty-four percent, and by 0.72 percentage points even when we assume an equipment share that produces an astronomical average gross return to equipment investment in 1960 of eighty-seven percent per year.

By contrast, even when the private return to schooling is set at ten percent per year, increases in schooling appear negatively correlated with total factor productivity growth, suggesting that we have perhaps overstated the return to schooling. Investment in non-equipment categories of investment does have a positive association of borderline significance with total factor productivity growth, but the association is only forty percent as strong as the association of equipment investment and TFP growth.

C. Investment Pessimism

The reason that even an astronomical gross private rate of return to equipment does not remove the correlation of equipment investment and TFP growth is straightforward. It springs from the "investment pessimism" of standard models like the one that underlies table 8. Suppose that total factor productivity is uncorrelated with and independent of investment. Begin with the identity:

(1) $$\Delta Y_t = (r + \delta)\Delta K_t$$

where r is the social net rate of return and δ is the depreciation rate. Equation (1) simply states that the (gross) increase in output produced from an increase in the capital stock is simply the gross rate of return on capital times the increase. Suppose that an economy initially in steady state receives a permanent boost I to its investment share, and that its capital stock evolves following:

(2) $$\Delta K_t = I - \delta K_{t-1}$$

Equation (2) simply states that the increase in the capital stock is equal to new (gross) investment minus depreciation on last period's capital.

In the first period all of the boost to investment will show up as an increase in the capital stock: $\Delta K_1 = I$, and $\Delta Y_1 = (r+\delta)I$. In the second period investment will still be running at its higher pace, boosted by I, but because K_1 is higher than K_0 depreciation will be higher than it was in steady state. The increase in the capital stock will be less: $\Delta K_2 = (1-\delta)I$, and $\Delta Y_2 = (r+\delta)(1-\delta)I$. The increase in the capital stock will become smaller and smaller and the stock will converge to:

(3) $$K_{steady\text{-}state} = I / \delta$$

And so the maximum boost to the output *level* that can result from a permanent boost to investment is:

(4) $$Y_{steady\text{-}state} = \{(r+\delta) / \delta\}\{I\}$$

A one percentage point boost I in investment can thus induce no more than a $(r+\delta) / \delta$ percentage point boost in the *level* of output—and thus no more than a $(r+\delta)/(\delta T)$ boost to the growth rate of output over a T-year period. Because equipment capital depreciates so rapidly and d is so high, even astronomical private rates of return on equipment cannot account for any substantial correlation of growth and investment rates: to account for such a correlation in a setting in which investment is cause and not effect, we need to drop the assumption that TFP is independent of investment.

IV. How Should We Interpret the Growth-Equipment Nexus?

A. Is the Association Due to Omitted Variables?

One cause of a strong association between equipment investment and growth is the omission from the set of independent variables of some other important growth-causing factor that happens to be correlated with equipment investment. Thus a high equipment investment coefficient does not necessarily imply a very strong structural association of equipment with growth.

Table 6 showed that the addition of some additional variables did not affect the size of the equipment coefficient: neither the introduction of school enrollment rates, continent dummies, nor the variables of Barro (1991) led to a dilution of the equipment coefficient. However, the continued strength of equipment investment when measurements of additional factors are added to the right hand side does not eliminate the possibility that equipment is a proxying for one or more of these factors. Our measurements available are all noisy. It is conceivable for, say, equipment investment to be more highly correlated with the acquisition of skills by the labor force in formal education than measures of school budgets or enrollment rates. Then equipment investment would be a better proxy of school-based investment in human capital than direct measures of schooling themselves. In such a situation the inclusion in the regression of schooling might not significantly reduce the equipment coefficient even if the bulk of growth-equipment nexus did arise from equipment’s role as a proxy for education.

We do not believe that this omitted variable bias could be a major source of the high regression coefficient on equipment investment in large part because of the low partial correlations between equipment investment and our measures of the alternative additional factors. Table 9 lists some sample partial R^2s of equipment investment with trade, education, and public investment variables. All are small—only one is as large as 0.1. Thus the variation in equipment investment, considered as a proxy, accounts for only a trivial proportion of the variation in these other factors. More than ninety-five percent of the variation in schooling measures needs to be "noise" for equipment investment to be a better proxy for education than measured schooling. More than ninety percent of the variation in trade and openness measures needs to be "noise" for equipment to be a better proxy than measured trade.

Table 9
Partial R^2s of Equipment Investment and Alternative Factors
(Controlling for Labor Force Growth, Productivity Gap, and Non-Equipment Investment)

Variable	Partial R^2
1960 Secondary School Enrollment	0.032
1960 Primary School Enrollment	0.052
Public Investment	0.010
Foreign Trade Share of Output	0.122

It is, of course, possible that the growth-equipment investment association is in large part a proxy for some growth-producing factor other than the simple acquisition and installation of capital equipment. Our prior is that the association is so strong because equipment investment is the best proxy available for the increase in worker skills and in organizational competence arising from hands-on experience at using new technologies and capital goods—that it is a proxy for human and organizational capital of a kind not easily produced by formal education. But if the equipment investment coefficient arose because equipment was a proxy for formal education, or for public investment, or for openness, then the partial R^2s in table 8 should be much higher: one variable cannot be a proxy for another if they are essentially uncorrelated.

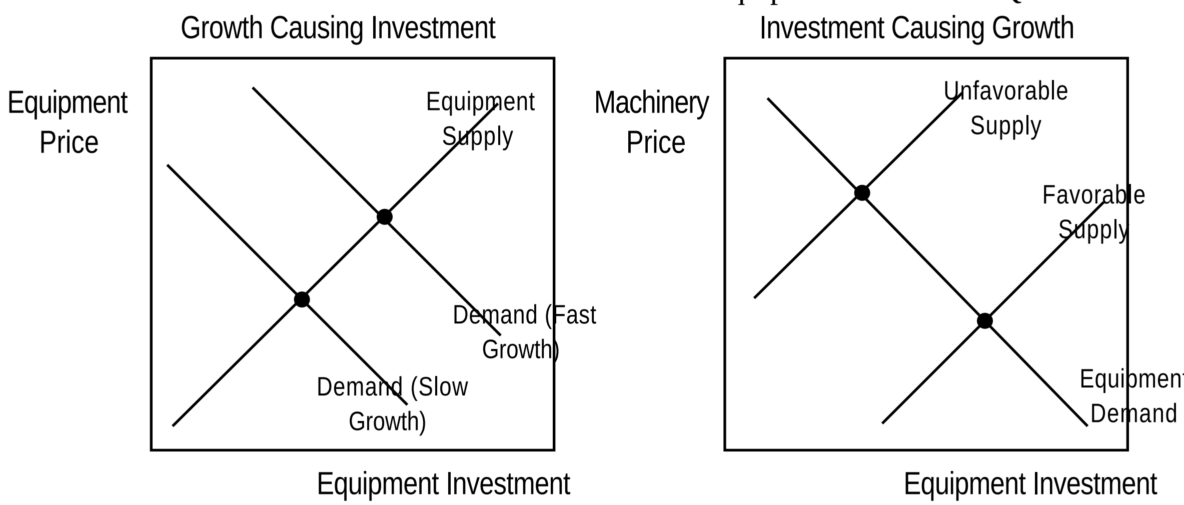
B. Is the Association Causal?

1. Prices and Quantities

Does the growth-machinery nexus arise because equipment investment causes rapid growth, or that rapid growth induces high equipment investment? Here we argue the case for seeing the growth-equipment link as a causal one running from investment to growth. The most powerful piece of evidencefor attributing causal significance to the equipment-growth nexus is the negative association between equipment prices on the one hand and equipment investment and growth on the other. If high rates of investment were a consequence rather than a cause, one would expect equipment prices to be higher in rapidly-growing countries because of strong demand pressing on the limits of supply.

This argument is simple supply-and-demand. Fast growth could increase equipment investment by raising profits and shifting the derived demand for equipment to the right. This would move the economy upward and outward along the supply curve, as shown in the first panel of figure 9. In such a case, rapid growth goes together with high equipment investment and high equipment prices.

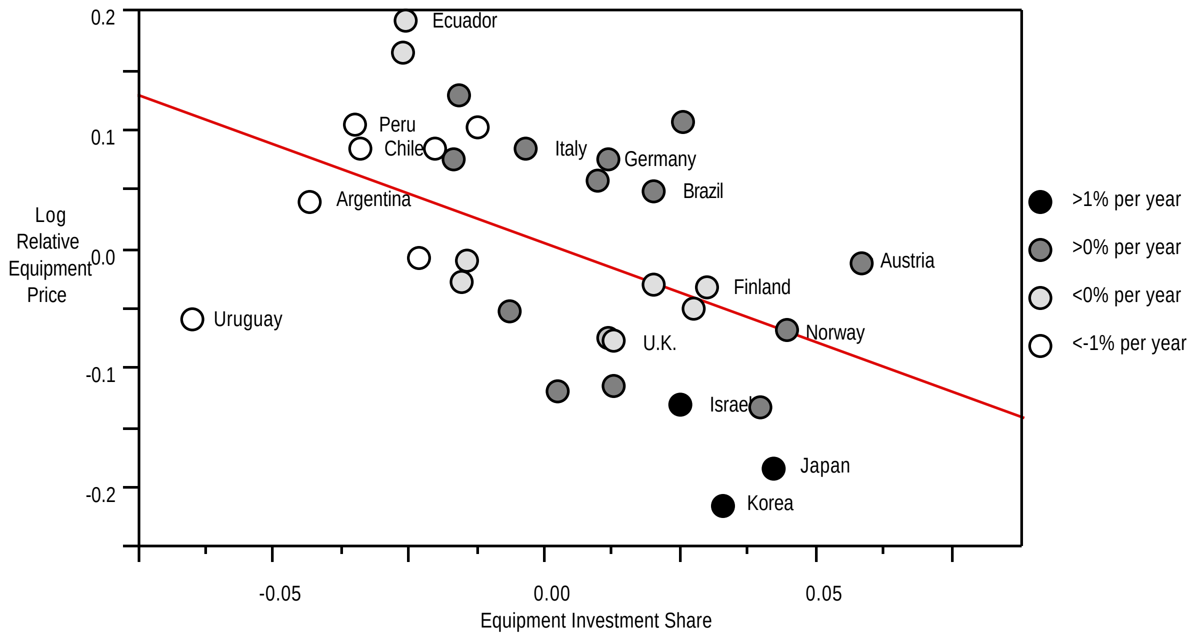
Figure 9
Identification from the Correlation of Growth and Equipment Prices and Quantities



We do not see such a pattern. Figure 10 shows, for 31 of the countries in our high-productivity sample, the association of equipment prices, quantities, and output per worker growth rates. The vertical axis plots the relative price of machinery and equipment in 1980, as estimated not by us but by Aitken (1991), controlling for current output per worker levels. The horizontal axis plots our estimates of 1960–85 equipment investment shares of GDP, once again controlling for output per worker levels. The kind of marker plotting the point contains information about the GDP per worker growth rate, once again controlling for output per worker levels: whether the residual growth rate is less than -1.0 percent per year, greater than -1.0 but negative, positive but less than 1.0 , or greater than 1.0.

Of the seven economies with growth rates (controlling for initial GDP per worker levels) in the slowest group, six are in the upper left corner of figure 10: with higher than average relative machinery prices, and lower than average equipment investment rates. All three of the fastest growing economies are in the lower right quadrant, with higher than average equipment investment rates and lower than average relative machinery prices. In our eyes, at least, high equipment appears more the result of favorable supply than of high demand induced by rapid exogenous growth.

Figure 10
Identification from the Correlation of Growth and Investment Prices and Quantities



2. Instrumental Variables

Further evidence the strong association between equipment investment and growth may well be a causal, structural association comes from instrumental variables estimates of the strength of the growth-equipment nexus. Any claim that the relationship running from machinery to growth is *causal* is a claim that a given shift in equipment investment—however engineered—will be associated with a constant shift in growth. The next best thing to direct experimental evidence is the examination of different aspects of variation to see if components of equipment investment driven by different factors have the same impact on growth. We examine the relationship between growth and various components of equipment investment associated with different aspects of national economic policies.[28]

[28]By examining the coefficient produced by different two-stage least squares regressions of growth on equipment investment with different sets of instruments. This procedure can be viewed as an informal Hausman-Wu test of the proposition that the equipment-growth relationship is a structural one uncomplicated by omitted variables or simultaneity.

Table 10
Instrumental Variables Regressions of Growth on Equipment Investment, High-Productivity Sample

Equipment Instrument	Other Investment	Labor Force Investment	Log Productivity Growth	Gap	R^2 (2nd Stage)	SEE	n
Savings Rate	0.232	0.080	0.005	0.017	0.598	0.009	47
	(0.058)	(0.032)	(0.145)	(0.003)			
Relative Price of Equipment	0.251	0.073	-0.046	0.018	0.655	0.008	31
	(0.104)	(0.051)	(0.177)	(0.004)			
Tariffs and Non-Tariff Barriers on Capital Goods Imports	0.275	0.061	0.016	0.018	0.486	0.010	39
	(0.099)	(0.037)	(0.218)	(0.004)			

Table 10 reports regressions of growth on components of the variation in equipment investment. The coefficients measure the association between growth and that portion of machinery investment correlated with the instrument. We use three sets of instruments: the average savings share of GDP over 1960–85, our own estimates of the deviation of the real price of equipment from its expected value, and tariff and non-tariff barriers to equipment. No matter which of these dimensions we examine, the association of equipment and growth remains the same. Estimated coefficients range from 0.232 to 0.275. The similarity of the association with growth of each of these components of equipment strengthens the case that the equipment-growth nexus is a “structural” relationship, not generated because equipment is a signal that other growth-producing factors are favorable.

Figure 11
Partial Scatter Using Savings Rates as an Instrument

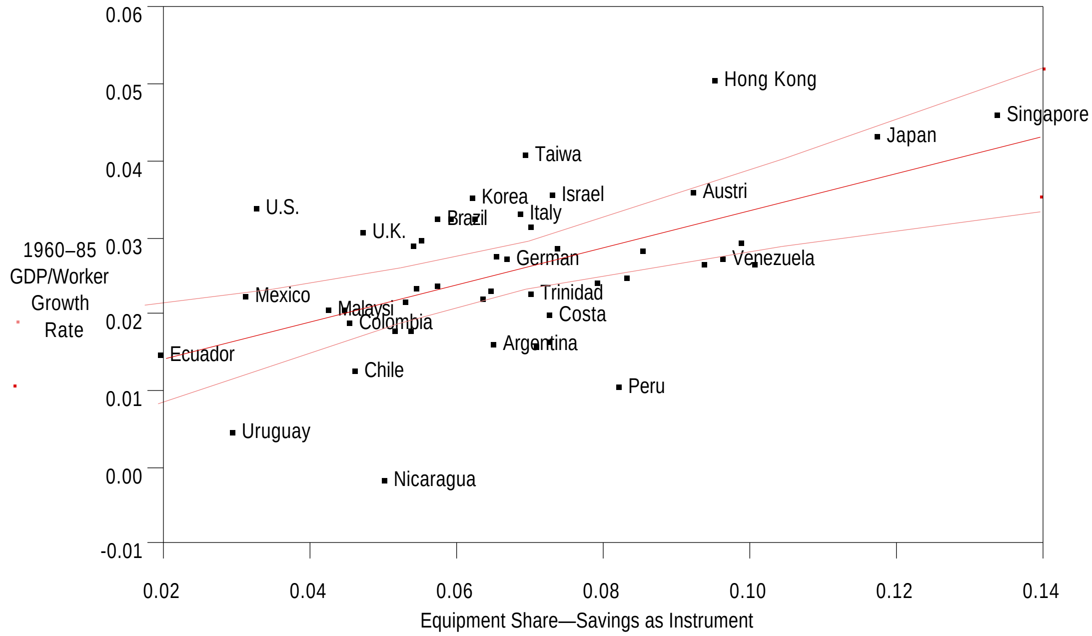
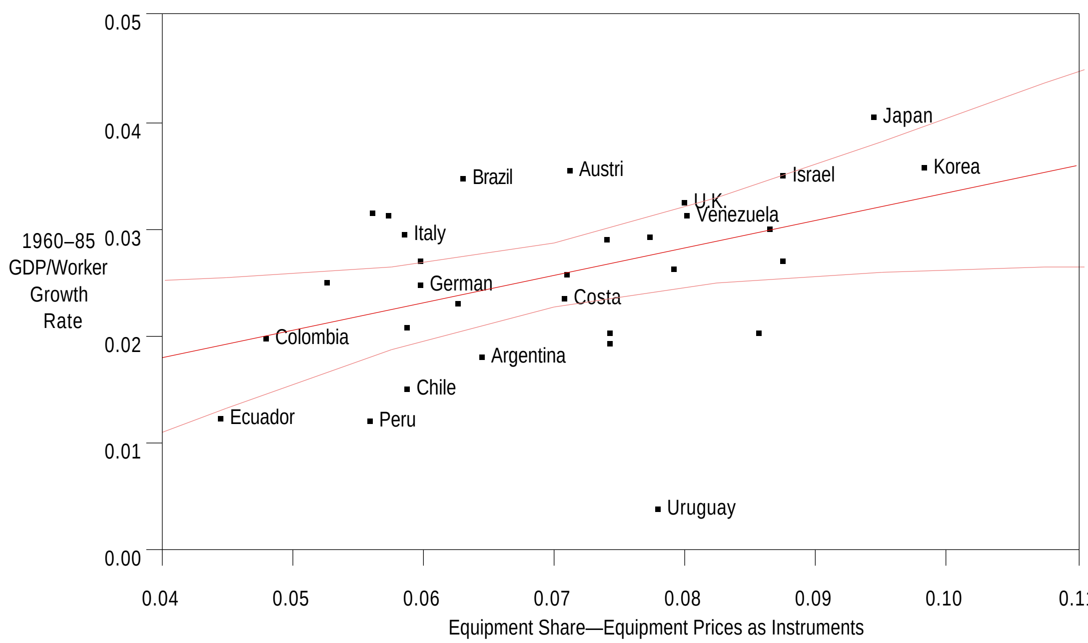
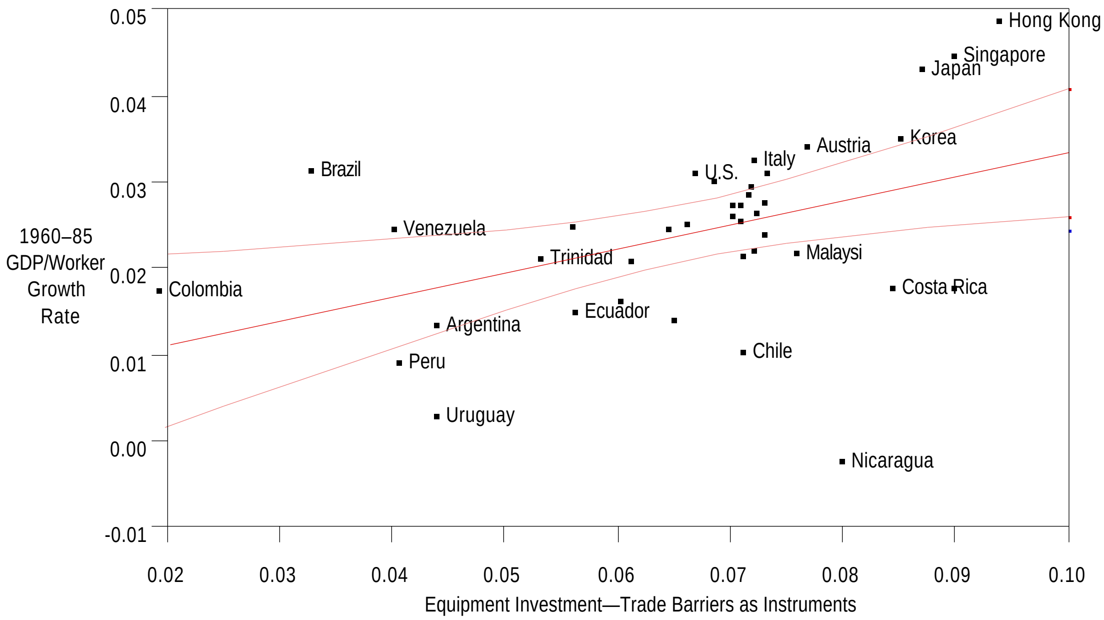


Figure 12
Partial Scatter Using Relative Equipment Prices as an Instrument



Despite the similarity of the estimated equipment coefficients, the instruments do capture different aspects of the variation in equipment investment. The correlations among the second-stage equipment investment values for the different instrumental variables regressions are not high. Controlling for non-equipment investment, the productivity gap, and labor force growth, there is a partial correlation of 0.43 between the savings- and price-based second-stage equipment variables, of 0.45 between the price- and the barrier- variables, and of only 0.28 between the savings- and the barrier- variables.

Figure 13
Partial Scatter Using Trade Barriers on Capital Goods as Instruments



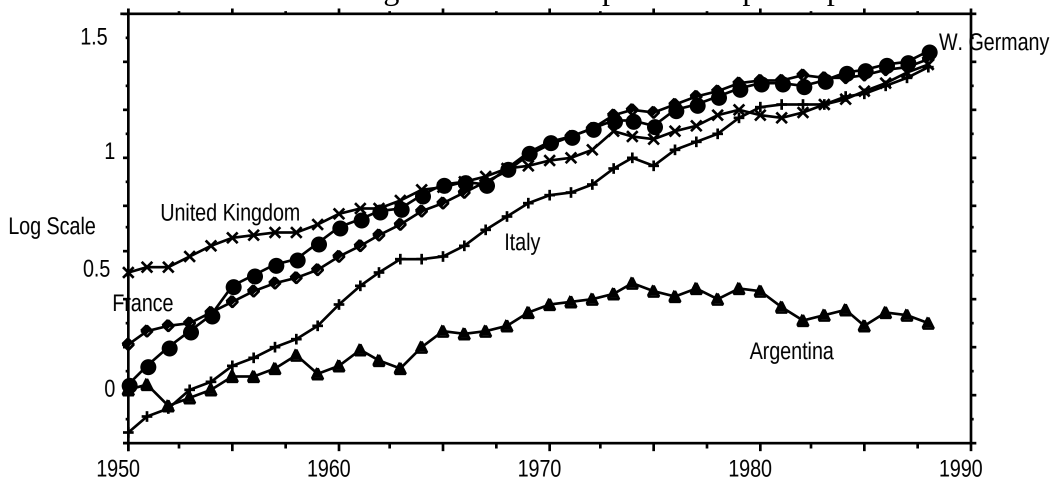
Figures 11 through 13 plot the partial scatters of equipment investment and growth from the second stage of the instrumental variables regressions of table 10. In the first line of table 10—which shows the effect on growth of that component of machinery correlated with aggregate nominal savings rates—the most influential observations are the Asian trio of Japan, Singapore, and Hong Kong with high, and Chile, Ecuador, Mexico, and Uruguay with low savings, equipment , and growth rates.

The second line—showing the effect of that component of equipment investment correlated with a low real price of machinery—has a somewhat different set of influential observations: Israel replaces Singapore in the set of the three most influential high-growth high-investment economies. The regressions in table 10 produce similar coefficients examining different components of the variation of equipment investment. It is unlikely that this would be the case if equipment were a signal and not an important cause of growth.

3. Case Studies: Argentina and Japan

One additional line of evidence that the association between machinery investment and economic growth is a causal one, and that high equipment investment is more than a signal that fundamentals are attractive, comes from analyzing exemplary case studies. Here we briefly consider the disappointing post-World War II growth history of Argentina, and the extraordinary success of Japan.

Figure 14
Post–World War II Argentine and European GDP per Capita Growth



Up to the late 1950s, Argentina was and for half a century had been a country about as rich as those of 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 1970s—even before the oil shock–induced borrowing sprees of the 1970s and the recession of 1980–82 led to the Latin American debt crisis, and the subsequent decade of decline in the 1980's—Argentina had become a third rather than a first world country. Figure 14, taken from De Long and Eichengreen (1991), shows the relative erosion of Argentine productivity and living standards according to the Summers-Heston estimates.

In the aftermath of the Great Depression and World War II Juan Perón gained mass political support by advocating a political program of national reassertion and populist redistribution. Perón embarked on a program of populist redistribution. Agricultural marketing boards were established to limit the price of food, and to keep rural monopolies from gouging urban workers. The growth of unions and the organization of workers was supported, in order to allow the urban working classes a fair chance to bargain against their employers. Urban wages were boosted.

Perón’s policies were popular. As Díaz Alejandro writes:

> [f]avoring domestic consumption over exports pleased the urban masses, and strengthening import restrictions pleased urban entrepreneurs. All who would lose, it appeared, were foreigners who had to do without Argentine wheat and beef and could not sell manufactures to Argentina, and oligarchs who had previously profited from the export-import trade and their association with foreign investors.

Perón’s policies twisted terms of trade against rural agricultural and in favor of urban industrial goods. Real wages for urban workers and profits for urban manufacturers rose, while real incomes of rural workers and landlords fell. Imports rose, and exports fell. By the late 1940s the resulting foreign exchange shortage gave Perón with only unattractive options. Controls were used to allocate newly-scarce foreign exchange. The raw materials and intermediate goods needed to maintain current operations had first priority, and kept flowing. But machinery and equipment, last in the queue, could not be imported in any quantity.

The early 1950s saw a huge rise in the relative price of capital goods. Before 1948, Argentina’s relative price structure had been comparable to that of Australia or New Zealand. According to ECLA, producer durables prices increased relative to the output deflator by more than 150 percent between 1948 and 1953. Each percentage point of national product saved produced less than half as much in terms of real investment in producer durables. A sharp decrease in the rate of real capital formation in new machinery and equipment followed. According to Díaz Alejandro, the share of real producer durables investment in the 1950s was less than half what it had been even in the depressed 1930s.

Successor governments did not reverse Perónist policies: the forces he had mobilized had to be appeased. Argentinean governments throughout the post-World War II era remained committed to relative autarky, favoring urban over rural producers, terms of trade that disadvantaged rural producers, overvalued exchange rates, and import controls. This produced an extraordinary rise in the relative real price of machinery and equipment—and a consequent fall in the rate of investment in machinery and equipment capital stock. In Díaz Alejandro’s view this fall in machinery investment was the principal source of slow Argentinean growth after World War II. Argentina had a low TFP “residual” growth rate because it had a low rate of equipment investment:

> a good part of the residual arises from not fully taking into account quality changes in machinery and equipment.…Even when technological improvements are not embodied in capital… taking

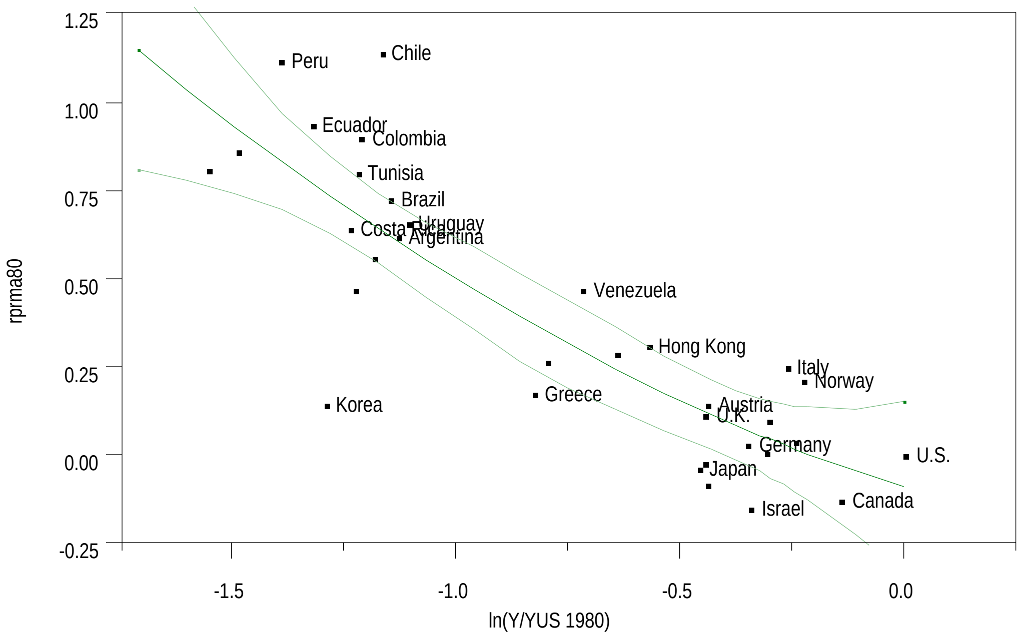
> full advantage…often requires the purchase of new machinery and equipment, while access to these capital goods will stimulate technical education and the use of better practices.

The post-World War II Japanese economic boom has been the most extraordinary positive episode in post-World War II economic history. Given the frequent emphasis on the strong structural differences between Japan and the other industrial market economies, it is noteworthy that Japan does not have a high positive residual in our regressions: the “Japan” point in our scatter diagrams is about where it ought to be given its initial level of output per worker, its rate of investment in machinery and equipment, and the cross-section pattern that holds for other countries. More than eighty percent of the 4.5 percentage point per year difference over 1960–85 between Argentinean and Japanese growth rates—a difference in growth that has led Japanese output per worker to quadruple relative to Argentinean in a generation—is attributed by our regressions to differences in rates of machinery investment. And in our regressions differences in relative starting points and in rates of equipment investment account for more than all of the difference between Japanese and American growth rates. Thus our scatter diagrams attribute Japanese rapid growth to its extraordinarily favorable factor supply fundamentals—its low producer goods prices and high equipment investment quantities. Growth has been further boosted by favorable demographics, a well-educated population, and its low post-WWII initial starting point. Little is left to be attributed to any qualitative difference in economic structures.

Japan’s high rate of equipment investment has many sources. A high savings rate has been one such factor. An openness to imports of technology, and of foreign capital goods has been a second.

A third factor, however, has been the low relative price of machinery and equipment in Japan. A large equipment investment effort—share of national product saved and spent on equipment—has been transformed into an extraordinarily large quantity of machinery and equipment investment by low relative producer durables prices. Figure 15 plots the log of the price of machinery and equipment relative to the price of GDP against real GDP per worker levels in the year 1980, from the 1980 UN ICP benchmark. Japan had a relative price of machinery and equipment in 1980 twenty percent below what one would have expected given its then level of output per worker. Such a relative price structure increases the rate of investment in machinery and equipment through two channels: first, the same quantity of consumption goods foregone purchases a greater quantity of investment goods; second, the more favorable terms of trade at which present consumption can be exchanged for income-producing physical assets may induce a high level of savings.

Figure 15
Log Relative 1980 Machinery and Equipment Prices

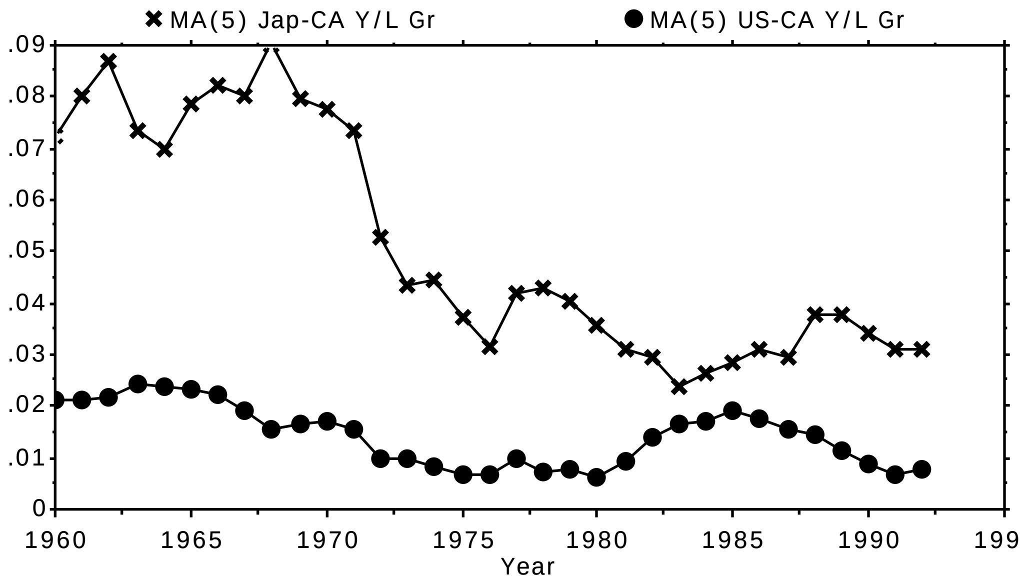


What are the sources of this price structure that appears so favorable for machinery invesment, and thus for economic growth? It is tempting to attribute it to Japan's Liberal Democratic Party. Prices of consumer goods are kept artificially high through regulation by LDP client bureaucracies interested in advancing the wealth of producer interests. But the prices of producer goods are not elevated: they are not the domain of the patron-and-client oriented LDP. Thus we would ascribe a potentially important role to MITI, as a bureaucracy oriented not toward enriching the interests of producers of capital goods, but instead focused on achieving value for the purchasers of capital goods whose productivity is to be enhanced through investment.[29] We suspect that the Japanese government, and MITI, have played a significant role in Japan's rapid growth. But we suspect that MITI has done so not by micromanaging industrial development but by blocking the effects of politics-as-usual in the

[29]Okimoto (1989) stresses that in "most cases, such pockets of inefficiency lie outside MITI's jurisdiction…" According to his analysis LDP members seeking to transfer wealth to sectors and ministers find it easier to do so if the sector is outside of the purview of the MITI ministry, with its strong interest in efficiency and development. Thus the MITI bureaucracy fulfills a valuable social role even though the industrial policies it pursues are often badly flawed. The most widely cited of MITI's failure to take a sufficiently long view is its reluctance in 1953 to grant Sony the license to purchase Western Electric's transistor technology.

investment goods markets. And the rest of the regulatory bureaucracy has aided development because unintentionally its attempts to enrich producer interests have helped create a structure of prices and incentives in which houses are expensive, rice is costly, but machinery is cheap.

Figure 16
5-Year Moving Averages of Cyclically-Adjusted Productivity Growth



From our perspective one of the reasons for the success of the Japanese economy has been that monopolistic high prices in other sectors, partially created by government action, have led to Japan's "getting relative prices right." High absolute levels of other prices have pushed the relative price of machinery down—and made it more "right" than complete *laissez-faire* would produce, in the sense of bringing private incentives to invest in equipment more closely in line with social returns.

The case of Japan speaks directly to an additional important issue: the validity of applying correlations estimated from a broad set of industrial economies to the very richest industrial economies at the technological frontier, where one might suspect *ex ante* that equipment investment has lower social returns because it cannot play an important role in transferring technology from richer, more industrialized economies. Japan today has material standards of living some thirty percent below those found in the United States. But its lag in material living standards appears due not to a lag in technology, but to Japan's low land per capita and to its low productivity in a large range of industries producing non-traded and agricultural goods. In Okimoto's (1989) estimation at least, productivity in these industries is low because of the diseases of the rent-seeking society—not because there is more modern technology elsewhere in the OECD that Japan has not yet absorbed.

Yet in spite of the lack of a technology gap, Japanese productivity has continued to grow significantly more rapidly than American productivity throughout the 1980s. Japan has devoted about eight percentage points more of GDP to equipment investment over the past decade, and has seen real productivity grow by twenty percentage points' worth relative to the U.S. This is a sign that whatever forces generate the growth-equipment nexus in our high-productivity samples of industrial economies is still at work at the very top of the industrial productivity ladder.

C. What Is the Social Rate of Return to Equipment Investment?

In our TFP growth regressions, a one percentage point increase in the equipment investment share of GDP is associated with an increase of approximately 0.13 percentage points per year in the TFP growth rate. Suppose that equipment investment yields a net private rate of return of ten percent that roughly corresponds to the return on business investments, and an associated gross rate of return of twenty-five percent per year. What then is the social rate of return to equipment investment?

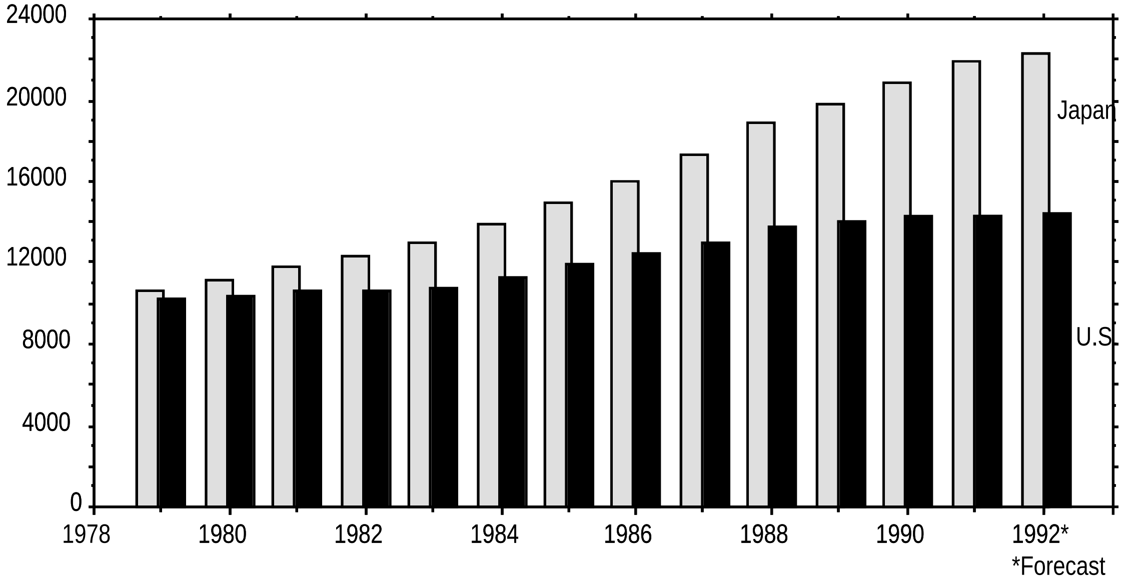
The exact calculation of the social rate of return hinges on the timing of the external 0.13 percent rise in TFP that may be induced by equipment investment. If this extra rise happens immediately—at the moment of installation, as new equipment is brought on line and workers and organizations learn the skills necessary to use it efficiently—then the net social rate of return to equipment investment is twenty-three percent per year: ten percent in extra privately-appropriable value created through capital deepening, and thirteen percent through the external effects induced.

If this extra rise is spread out over time proportional to the depreciated remaining value of the extra capital put in place, then the net social rate of return is lower because the productivity gains occur only in the future, and must be discounted. At the fifteen percent per year depreciation rate assumed for the benchmark parameters, the social rate of return is nineteen percent per year: pushing off the external productivity benefits of investment to future years by making them proportional to current capital services substantially reduces the present value of the external productivity gains induced. If the external productivity gains are all delayed until the tenth year after the initial investment—an extreme assumption, at which time the depreciated value of the investment goods put in place is only twenty-two percent of its initial installed value—then the net social rate of return compatible with a cross-section regression coefficient of .21 is as little as fifteen percent per year.

Our conclusion is that the cross-section regressions, if they will bear a causal interpretation, suggest *net* social rates of return from equipment investment in the range of twenty percent per year, under the maintained hypothesis that the large coefficient on equipment investment arises because equipment investment is a trigger of learning-by-doing and thus of substantial total factor productivity growth. To the extent that causality flows from growth to equipment investment as well as from investment to growth, the social rate of return will be somewhat lower. To the extent that most of the productivity gains from learning how to use and organize production with new machine technologies occur soon after their introduction (rather than equiproportionately over equipment's lifespan), the social rate of return will be somewhat higher. To be more precise would require a much sharper vision of the process of productivity growth and on-the-job-training than we possess.

If we believe that equipment investment has substantial external TFP growth effects that are proportional to the flow of capital services, then we can calculate the magnitude of that component of future productivity growth that will be induced in the future by capital already put into place: it is simply proportional to the current stock of machinery and equipment per worker. Figure 17 compares U.S. to Japanese equipment capital per worker stocks since the late 1970s using our extensions of the Summers and Heston database. It shows a large and growing gap that has opened in the past decade. Using our estimates of the strength of the growth-equipment nexus, the current edge Japan possesses in equipment capital per worker will generate an extra $1200 dollars per worker of productivity growth in Japan relative to the U.S. in the future, independent of any additional gap in future rates of equipment investment. From this difference alone, we suspect that the U.S. will be unable to match the productivity growth rate benchmark that the Japanese will set in the 1990s.

Figure 17
U.S. and Japanese Machinery and Equipment Capital Stocks per Worker (1985 International Dollars)



V. Conclusions and Implications

A. Summary

We have argued here, as we argued before in De Long and Summers (1991), that there is a very strong association between machinery investment and productivity growth. This strong growth-machinery nexus can be found in databases reaching as far back into the past as 1870. It is as strong in the economies and subsections of the post-World War II era not analyzed in our previous work as in the sample of De Long and Summers (1991). There is no statistical sign that it is confined to middle-income and newly industrializing economies. If nothing else, the example of Japan suggests that rapid total factor productivity growth and high equipment investment go together even in economies at the world's manufacturing technology frontier. We do not think that the associations we have documented in this paper are not relevant for U.S. economic policy just because U.S. TFP levels are among the world's highest.

All of our regressions show an association of machinery investment and output per worker growth much stronger than we would expect under the standard growth-accounting assumption that the return to investors is the marginal social product of investment in equipment, if we interpret the coefficient as the relative change in output growth rates induced by a shift in the rate of investment.

One possible interpretation of the growth-equipment investment nexus is that it arises because of the omission, or the poor measurement, of other factors making for rapid economic growth. We investigated the correlation between equipment investment and formal education, and between equipment and total investment. We did not find any sign that the high equipment investment coefficient arose because equipment was an extraordinarily good indicator of the accumulation of other factors of production.

We also used instrumental variables to estimate the causal force of the growth-equipment nexus. Our instruments were variables to a large degree determined by economic policy that directly affect machinery and equipment investment rates while only indirectly affecting output per worker growth. Barriers to imports of machinery and equipment are strong impediments to equipment investment, but have little direct effect on growth. Savings rates and relative equipment prices are also powerful determinants of investment, with only weaker direct effects on growth. The similarity of the equipment investment coefficients estimated using these three sets of instruments gives us confidence that the equipment investment-growth nexus is indeed a causal one.

We conclude that the bulk of the growth-equipment investment relationship arises because a high rate of equipment investment is a key cause of rapid growth. The most plausible mechanism is that workers' skills and organizations' capacities to handle technologies are largely learned-by-doing. And we estimate that the social *net* rate of return to investments in machinery and equipment is in the range of twenty percent per year.

B. Doubts

We are not certain that our interpretation is the correct one. One observation, especially, gives us pause: there is substantial evidence that the centrally-planned communist-ruled economies of the twentieth century commanded that huge fractions of GDP be devoted to machinery investment, yet they have not realized rapid productivity growth. If machinery investment does indeed have massive external benefits, then why didn't Stalin's Russia—apparently investing a greater share of total output in machinery over 1929–1973 than Japan did over 1950–1973—even begin to overtake the industrial west?

One possibility is that we have given an incorrect interpretation to our data. In spite of our attempts to control for outside sources of growth, it may be that the growth-equipment nexus arises not because equipment investment causes rapid growth but because high equipment investment is a signal that other, unmeasured fundamental factors that are also powerful causes of rapid growth are favorable. If this were the case, we would expect to see signs that high rates of equipment investment and rapid growth go together because demand for equipment is high when growth is high. This is not the case: high investment in equipment and rapid growth appear associated with favorable supply conditions for equipment, not with strong demand. Nevertheless, this remains a possibility.

We are attracted to a second possibility: one that attempts to resolve the apparent inconsistency between the strong cross-section correlation of machinery and growth in market economies and the failure of high rates of machinery investment to trigger rapid productivity growth in centrally-planned economies. A given investment in machinery can have large external benefits if learning-by-using helps to create a workforce experienced and competent at handling modern technologies, and helps organizations to develop the rules of thumb and standard operating procedures necessary to produce efficiently that other firms can imitate. If these are the channels through which machinery investment produces external benefits, then it makes sense that few such external benefits would be generated by investments in inappropriate technologies. There is no gain to creating a workforce trained at technologies that subtract value. There is no advantage in the opportunity to copy the operating procedures of a money-losing organization. This leads us to suspect that the largest external benefits from machinery investment will arise from those investments that make the highest profits.

This line of thought suggests that growth is likely to be increased by investment-promoting policies that were market conforming: policies that alter the marginal incentives of producers and investors and induce them to undertake machinery investment projects that had previously just failed to meet hurdle rates. Policies that command pre-chosen large-scale investments in machinery whether or not they meet direct cost-benefit tests are not likely to generate investment in kinds of machinery that have high private benefit-cost ratios. Perhaps we should not be surprised when the commands for more machinery investment issued by Joseph Stalin lead to an economic structure in which workers and organizations have skills and operating procedures that are value-subtracting.

Thus we are attracted to an interpretation that stresses the importance of machinery investment in a market context. Market signals and allocation processes may well be essential to generating the type of machinery investment that is associated with rapid productivity growth. One of the underlying themes of this paper has been a contrast between investment and “investment effort.” In some cases, for example post-World War II Argentina, a substantial “investment effort” in terms of the present consumption sacrificed to finance new purchases of machinery and equipment has led to little in terms of actual investment, defined as capital goods put into place and then intensively used in production. High prices for machinery and equipment transformed a healthy savings rate into an anemic real investment rate. In Japan, conversely, a favorable relative price structure helped transform an already healthy investment effort into a very strong performance in terms of actual investment. Perhaps we should interpret the relatively meager gains from Joseph Stalin’s investment program as due to the orders of magnitude larger gap between investment effort and investment outcomes under a system based on command and force.

C. Economic Policy

How best can rates of equipment investment be enhanced? First, the example of the centrally planned Communist economies that attempted to devote enormous resources to equipment investment and yet saw few productivity gains should lead governments to avoid non-market policies to boost equipment investment. Even if the equipment-growth nexus is a causal one, it appears to be one that is potentially swamped by the enormous inefficiencies that command allocation processes generate. Incentives that conform to a market framework appear vastly preferable to commands that replace such a framework.

Second, governments must avoid anti-equipment incentive policies. Countries where property rights are not respected are likely to have a difficult time attracting equipment investment. Countries where macroeconomic policies are unsustainable and leave the ultimate financing of current expenditures in doubt are also likely to see low rates of equipment investment. Large budget deficits create substantial uncertainty in future tax policies and inflation rates: to cut current taxes while increasing spending is not to reduce but to randomize tax burdens. Governments that follow such cut-and-borrow policies should not be surprised when forward-looking firms and investors respond not by increasing but by reducing saving and investment. The best policy for the supply-side is a budget surplus over the business cycle.

More specific policies that discriminate against equipment include "industrial policies" that protect established firms at the expense of new entrants from home or abroad, and that force purchasers to pay higher than world prices for the products of domestic capital goods industries. All over the world governments in the post-WWII era have sought to encourage industrialization and growth by providing protection and subsidies for what they view as their high value-added industries. In almost every case governments and their supporters have pointed to the limitations of *laissez-faire* theory, and called for policies that wrench resource allocation away from static "Ricardian" efficiency in the interests of attaining "Schumpeterian" efficiency.[30] But outside of East Asia, and possibly Brazil, such policies appear to have been disastrous. One attractive interpretation is that Pacific Rim industrial policies have managed to combine subsidization of equipment investment and exports while maintaining a ferocious degree of domestic competition. Many industrial policies around the world appear to us to have confused support for modern *industry* with whatever enriches one's current (and vocal) population of *industrialists:* this seems to us another potential road to disaster.

Still other policies with an anti-equipment bias include tax rules that subsidize assets that can easily be levered. Because of transactions costs in second-hand markets and the dedication of equipment to particular uses, pieces of equipment are frequently more difficult to use as collateral for debt than are structures investments. On the labor market side, policies that make it very costly for firms to substitute capital for labor are also likely to inhibit growth by discouraging equipment investment. To the extent that workers in the future will gain high wages by virtue of their skills in handling modern machine technologies rather than by occupying niches in which quasi-rents can be captured, it is not even in labor's short-run interest to press for a reduction in the capital-labor ratio.

Third, governments can promote equipment investment in a number of ways. Given that international capital markets remain imperfectly integrated, increases in national savings—whether induced by deficit reduction, or by policies that increase private savings—translate into some increased

[30]See, for example, Johnson, Tyson, and Zysman (1989).

equipment investment. Believers that international capital markets will not channel substantial long-run flows see an extra 35 cents of equipment coming from each dollar of deficit reduction or increased private savings. Believers in open capital markets would divide that estimate by two, or three.

Measures that reduce the tax burden on new equipment investments are likely to be especially potent in maximizing the equipment investment engendered per dollar of government revenue foregone. While we have little confidence in any of the formal quantitative estimates, we think that each dollar of revenue lost from an equipment investment taxs credit would generate an extra dollar of equipment investment—with a larger benefit-cost ratio for an incremental investment tax credit. However, tax laws crafted to reward only increments quickly become self-defeating as accountants and private lawyers create new strategies, instruments, and organizational forms. And to the extent that investment tax credits are not financed by spending cuts or other tax increases, the resulting addition to the deficit places an increased drag on private investment.[31]

There is one final, important consideration: in a sense equipment is not a very fixed factor. At a depreciation rate of fifteen percent, a given investment has already contributed more than half of its capital services to production within three and a quarter years after installation; at a depreciation rate of twelve percent, the halfway mark in provision of capital services occurs after four years. Pieces of equipment are, therefore, less durable from the perspective of their permanent contribution to production than are many employees. Equipment has always been one of the most mobile factors of production in the long run. If equipment is uniquely valuable as a catalyst for learning-by-doing and skill upgrading, then in view of the mobility of equipment any government that wishes to have its economy grow rapidly must take extraordinary pains to make sure that investors in equipment see it as a hospitable environment. Ample provision of infrastructure, a skilled, trained, and motivated workforce, and low taxes on new capital investments may well, in a world where equipment investments are mobile, much more than pay for themselves by virtue of the extra equipment investment that their provision induces.

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[31]They will, however, change the mix of investment toward equipment, which may have substantial benefits

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