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# How do National Policies Affect Long-run Growth?

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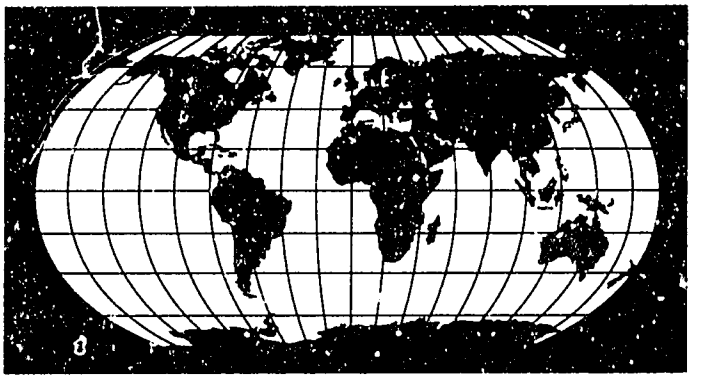

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*"How Robust is the Growth-Machinery Nexus?"*

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# How Robust Is the Growth-Machinery Nexus?

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## I. Introduction

This paper provides evidence showing, for a variety of samples of economies and for a variety of periods, that in the cross-country distribution of growth rates there is a very strong connection between machinery investment and productivity growth. In this paper we continue the research project we began in "Equipment Investment and Economic Growth" (De Long and Summers, 1991).

In that paper we used data from Summers and Heston (1988, 1991) and from detailed benchmark estimates of national economy price and quantity structures from the U.N. International Comparison Project. We demonstrated that in that particular dataset covering the 1960–85 period, both a 61-economy sample including both rich and poor nations and a 25-economy sample of rich nations showed a very strong connection between growth and investment in machinery and equipment.

Here we use additional data to show that this strong growth-machinery nexus was not an artifact of the particular cross-section or the particular sample period of De Long and Summers (1991). Here we show that a strong growth-machinery nexus can be found in databases reaching as far back into the past as 1870. Moreover, the patterns found in De Long and Summers (1991) for the post-World War II era hold not just for the cross-section sample analyzed there but for other post-World War II economies not in our previous database as well. And the patterns hold for post-WWII years outside our previous 1960–85 sample.

These findings give our earlier argument enhanced authority. The models we use and regressions we estimate here were specified in 1990, long before we had begun to collect the additional data underlying the results reported in this paper. Yet our specifications, *ex ante* from the standpoint of the data we have collected since 1990 analyzed, fit this paper's data as well as they fit the data analyzed in De Long and Summers (1991). They 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 addition, the data we analyze in this paper supports our belief that the growth-machinery nexus arises from strong *causal* links between machinery investment and growth. We report instrumental variables regressions, using as instruments variables that are in large part the results of policy choices made by governments, and that have direct effects on machinery investment rates and only indirect effects on output per worker growth. Such instrumental variables regressions reveal the same association between growth and machinery as our least-squares regressions. This strengthens our confidence that the bulk of the growth-machinery investment relationship arises from a

causal nexus between machinery and growth, and that policies undertaken to generate more or less machinery investment by altering the incentives of investors and firms in market economies have large effects on economic growth rates.

We organize the argument of this paper in five sections, including this brief introduction. The second section summarizes our previous work. The third section presents evidence from additional periods outside the 1960–85 sample . analyzed in De Long and Summers (1991). The fourth section presents evidence from additional nations not included in our previous cross-section.

The fifth section discusses interpretations. In it we argue that the association of growth and machinery is much stronger than one would anticipate if the source of the connection were the added production that growth-accounting studies attribute to capital. We also present instrumental variables results that strongly speak for the claim that policies that succeed in altering the incentives of market participants and changing rates of machinery investment have large effects on growth. We also discuss informal and anecdotal evidence suggesting that policy interventions to change the rate of machinery investment that are not market-conforming—of which the most substantial have been the policies of "forced industrialization" undertaken in the centrally-planned economies of the twentieth century—yield much lower benefits.

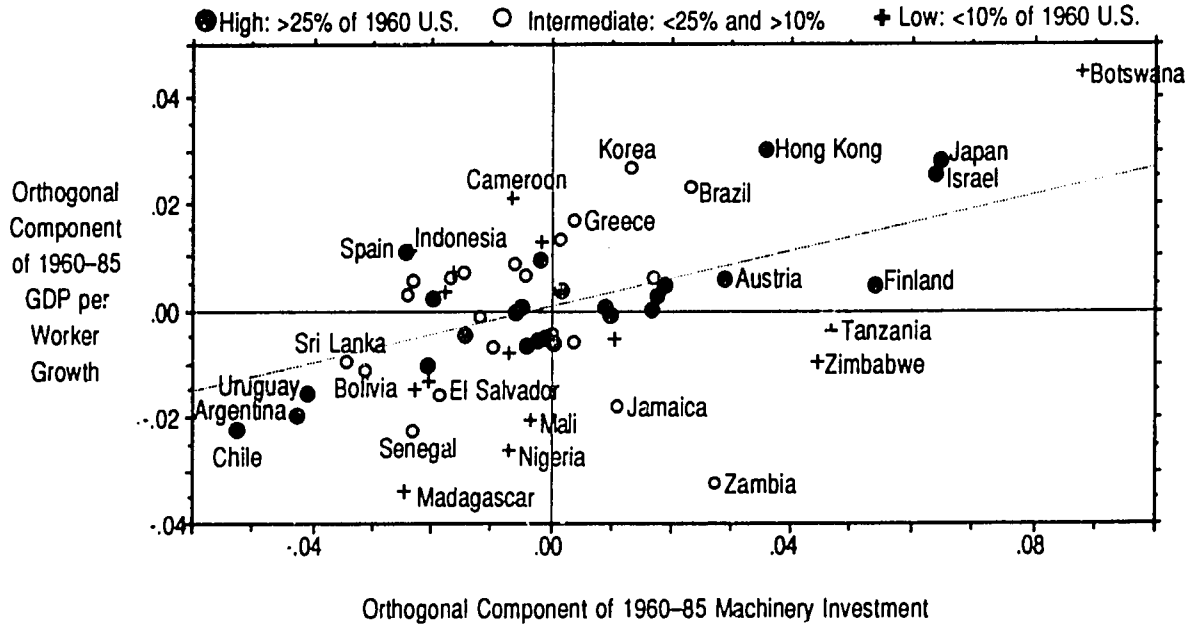
The sixth section provides a brief recapitulation of our main points.

## II. The Growth-Machinery Nexus: Previous Evidence

De Long and Summers (1991) regressed the growth rate of GDP per worker over 1960–85 (in international dollars as estimated by Summers and Heston (1991)) on the

estimated share of GDP devoted to machinery investment over 1960–85.[1] Our basic regressions controlled for three of the most obvious growth-related factors: labor force growth, other forms of investment, and the productivity gap vis-a-gis the world's industrial leaders. Labor force growth determines the degree to which investment equips new workers with capital rather than raising the capital-labor ratio. The productivity gap vis-a-vis the richest nations measures the potential gains from the adoption of best-practice technologies and organizations. The share of GDP devoted to non-machinery investment measures the rate of non-machinery capital accumulation.

**Figure 1**
**Partial Scatter of Growth and Machinery Investment from De Long and Summers (1991)**




[1]We estimated the machinery and equipment investment share by multiplying the average share of investment in GDP by ICP benchmark-year measures of the share of investment devoted to machinery and equipment.

Figure 1 and table 1 present a summary of our results in De Long and Summers (1991), using our sample of the 61 non oil exporting nations for which we had U.N. ICP data to use to construct estimates of machinery investment over 1960–8.[2] Figure 1 plots the partial scatter of machinery investment and GDP per worker growth. Its vertical axis measures that component of 1960–1985 GDP per worker growth orthogonal to the three "control" independent variables in the basic regression shown in the first column of table 1. Its horizontal axis measures that component of the 1960–85 real machinery investment share orthogonal to the same three controls. The figure shows point-by-point the information on the partial correlation of machinery investment and GDP per worker growth contained in the cross-country sample of De Long and Summers (1991).

Table 1 reports a sampling of regression equations estimated in De Long and Summers (1991). The first column provides our basic specification, using just machinery investment and our three most basic controls as independent variables. The second sample reports regressions for a high-productivity sample containing just those nations with 1960 levels of GDP per worker more than twenty-five percent of the U.S. value; such economies had already exhibited substantial economic growth over the previous half-century and possessed the human and physical infrastructure necessary to take advantage of modern machine technologies. The third column reports a regression including 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. The fourth column reports a regression including continent

[2] And using our 1991 vintage of machinery investment estimates

dummies. And the last two columns report regressions for subperiods of the 1960–85 period.

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

| Independent Variables | 1960-85 Basic Regression | High-Productivity Sample | Barro Variables Included | Continent Dummies Included | 1960-75 | 1970-85 |
|---|---|---|---|---|---|---|
| Machinery Investment Share of GDP | 0.265 (0.065) | 0.337 (0.054) | 0.275 (0.070) | 0.288 (0.072) | 0.279 (0.086) | 0.276 (0.082) |
| Non-Machinery Investment Share of GDP | 0.062 (0.035) | -0.015 (0.033) | 0.029 (0.037) | 0.022 (0.038) | -0.011 (0.043) | 0.040 (0.047) |
| Labor Force Growth | -0.031 (0.198) | -0.002 (0.146) | -0.001 (0.203) | 0.143 (0.285) | 0.019 (0.233) | -0.217 (0.270) |
| GDP per Worker Gap vis-a-vis the U.S. | 0.020 (0.009) | 0.030 (0.009) | 0.039 (0.013) | 0.029 (0.012) | 0.039 (0.016) | 0.038 (0.017) |
| $R^2$ SEE | 0.291 (0.013) | 0.662 (0.008) | 0.391 (0.012) | 0.385 (0.012) | 0.263 (0.015) | 0.236 (0.016) |
| | 61 | 25 | 61 | 61 | 61 | 61 |

In all of the regressions in table 1, machinery investment has a strong and precisely estimated association with economic growth. In the basic regression in column one, the control variables—initial GDP per worker levels, labor force growth rates, and non-machinery investment rates—each account for less than 5 percent of the variability of output per worker growth rates. By contrast, differences in machinery investment account for a quarter of the growth rate variance. An increase of four percentage points in the share of GDP devoted to machinery investment is associated with an increase in the growth of GDP per worker of 1 percent per year. Over the 25 years of the sample such an increase in growth rates cumulates to a difference of 30 percent in the final level

of GDP per capita: differences in machinery investment are associated with substantively important differences in productivity growth.

To put this association in perspective, this implies that a difference in machinery investment rates of one cross-country standard deviation is associated with a difference in growth rates of nearly half of the cross-country standard deviation. Differences in machinery investment are associated with a sizeable share of differences in output per worker growth rates.

Other writers have stressed still other factors as potential influences on growth. Alesina and Rodrik (1991) endogenize politics and trace links from high inequality to slow growth. Agarwala (1984), Balassa (1970, 1982), and many others have documented links between openness to international trade and growth. Still other factors that have received emphasis are the allocation of entrepreneurial talent to positive- as opposed to zero-sum activities (Murphy, Shleifer, and Vishny, 1991), the appropriate mix of human capital (Kremer, 1991), financial policy (Levine, 1991), and incentives for research and development (Romer, 1989). We argue in De Long and Summers (1991) that while these other factors have significant and important partial correlations with growth,[3] their inclusion in the list of independent variables has little effect on the estimated magnitude of the machinery-growth nexus.

The strong association means that differences in machinery investment account in a statistical sense for essentially all of the extraordinary growth performance of many fast-growing nations—for example, Japan—relative to the sample as a whole. Conditional on the initial GDP per worker gap and the achieved rates of growth of the labor force, Japan has achieved a relative GDP per worker growth rate edge of 2.2 percent per

[3]But note that in many cases their coefficients are not robust to changes in the specification. See Levine and Renelt (1992).

year over 1960–1985 relative to the average pattern seen in the sample, given the values of the control variables in the basic regression. Conversely, deficient machinery investment can account in a statistical sense for the relatively poor performance of many slow-growing nations. Argentina, for example, has suffered a relative GDP per worker growth rate deficit of 2.1 percent per year over 1960–85, relative to the sample average. In both the case of Argentina and the case of Japan, more than four-fifths of this difference is accounted for in the framework of table 1 by their high or low quantities of machinery investment.

The results of De Long and Summers (1991) leave open only two potential reasons for doubting that machinery investment is indeed a key factor in the economic growth of market economies. The first reason is that there is a possibility that causality runs the other way—from fast growth to high machinery investment rather than from high machinery investment to rapid growth. We provided a number of pieces of evidence that investment rates were the cause and growth rates the effect. Of these, the most powerful was the negative association of machinery prices with machinery quantities and with growth: if high investment were induced by high demand for capital goods as a result of rapid growth driven by other factors, then machinery prices should be high—not low—in fast-growth high machinery-investment economies. But the issue of causality is a delicate and important one that no collection of evidence can definitively close.

The second reason is that in initial exploratory studies of any topic there is always a dynamic relationship between the specification and the data.[4] Specifications are

[4]In this case, as we noted in De Long and Summers (1991) we omitted transport equipment from our key investment aggregate not on theoretical grounds but because of its relatively low correlation from growth. In addition, we had begun our paper believing that it would focus on the relationships between a price structure favorable to investment and economic growth. Our shifting of topic to document the association of machinery investment and growth was a result of the extraordinary strength in our dataset of the relationship between the quantity structure of an economy and its rate of growth.

always adjusted at the margin to fit the peculiarities of the particular data set. And the questions ultimately asked are shaped by the questions the database appears capable of answering. Given this interplay, standard t-statistics overstate the confidence with which one can draw conclusions. As a result, tests of empirical hypotheses on newly constructed, independent datasets are very valuable. Hypotheses that pass such tests on new, independent data are thereby endowed with extraordinary force. We now turn to the task of providing such tests.

## III. The Growth-Machinery Nexus: Evidence from Additional Periods

In this section we show that the patterns found in De Long and Summers (1991) for the 1960–85 subperiod of the post-World War II era hold not just for that period but for other periods as well—the decade of the 1950's, the (very short) period since the end of the De Long and Summers (1991) sample, and most important for a dataset containing evidence on machinery investment in the very long run since 1870 as well. The next section continues the task of providing tests of the hypotheses of De Long and Summers (1991) on new, independent data. In it we show that the patterns hold not just in the cross-section sample analyzed by De Long and Summers (1991) but also for a sampl made up of other economies not included in our previous database.

The regression specifications we estimate here were published, specified, and fixed as of early 1991, long before we had begun to collect the additional data underlying our results. Thus the empirical results in this and the following section greatly enhance the authority of our earlier findings. In this paper our *ex ante* specifications fit the data we

have collected more recently as well as they fit the data we originally analyzed in De Long and Summers (1991).[5] In all the samples and over all of the time periods that we have examined, there is a strong association between machinery investment and output per worker growth. This association is much stronger than we would expect to see under the standard growth-accounting assumption that the return to investors is the marginal social product of investment. Our results strongly support "new thinking" in the theory of economic growth, largely derived from the work of Paul Romer,[6] which stresses the connection between productivity growth and investment broadly defined, and sees large gaps between the private profitability and the social utility of various components of investment.

*Machinery and Growth in the Very Long Run*

De Long (1992) argued that machinery investment and growth were closely associated not just in the post-World War II period but in the longer-run as well by regressing growth on machinery investment in a small very long run panel of currently-industrialized nations. The sample was of necessity small. It consisted of six industrial nations for which data are available— Canada, Germany, Italy, Japan, the United Kingdom, and the United States—plus a seventh nation once among the world's leaders

[5]One dimension along which the specification of De Long and Summers (1991) was explicitly *ex post* was its omission of transport equipment from its equipment aggregate. As Jong-Wha Lee (1992) has pointed out to us, Liberia and Panama appear to have enormous relative amounts of investment in transport equipment because of the large share of the world's ocean-going fleet registered in those two flag-of-convenience countries. Nevertheless, we continue to exclude transport equipment from the machinery investment aggregate studied in this paper in order to gain the advantage of a specification fixed and known to have been fixed *ex ante*.

[6]Paul Romer (1986), "Increasing Returns and Long-Run Growth," *Journal of Political Economy* 94 (October), pp. 1002–37; Paul Romer (1990a), "Capital, Labor, and Productivity," *Brookings Papers on Economic Activity*; and Paul Romer (1990b), "Endogenous Technological Change," *Journal of Political Economy* 98:5 (October), pp. S71–109.

in living standards: Argentina.[7] On the other hand, the panel covered most of economic growth since the industrial revolution. It extended from 1870 to 1980.

De Long (1992) showed a close association between output per capita growth and a "net concept" of machinery investment—the change in the gross machinery stock.[8] Here we demonstrate that such a close association holds for this very long-run panel between output per worker growth and *gross* machinery investment as well. The estimates of machinery (and non-machinery) investment used in De Long (1992) are transformed into estimates of gross machinery (and non-machinery) investment as a share of GDP by assuming an eight-year life for machinery and a thirty three-year life for structures.[9]

There are three differences between the data used here and those used in De Long (1992). First, here we use output per worker. Second, here we use not a net but a gross investment concept of machinery investment. Third, here we use the relative price structure for GDP, machinery investment, and investment in structures of the U.S. in 1929 rather than the U.S. in 1970 as our benchmark for determining real investment shares of national product.

The first two of these changes from the specification of De Long (1992) were

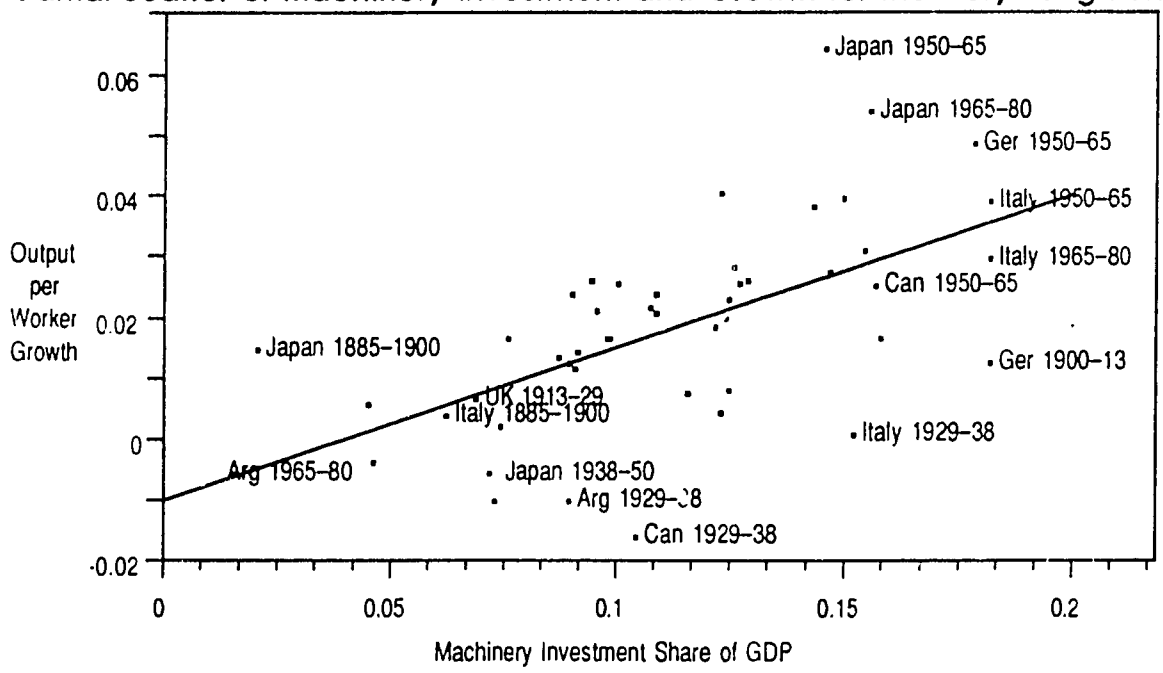
[7]The sample was restricted to such a narrow base because of data availability. Long-run national product estimates of the necessary quality are rare, for economic historians are luxuries usually found only in rich nations. Any quantiative examination of the correlates and determinants of long-run growth is subject to severe sample-selection biases that effectively remove from consideration those issues and factors which Abramovitz (1986) groups under the heading of "social capability." The nations for which long-run data on factor accumulation are available had a pre-twentieth century history of experience with entrepreneurship, market exchange, and early modern technologies. Thus—as De Long (1992) noted—any conclusions drawn from such a narrow base are somewhat fragile.

[8]De Long (1992) gave two reasons for his specification: first, that the change in the gross capital stock is the appropriate measure of the outward shift in a production function made possible by new investment and is thus the theoretically most favored concept of investment; second, that (as Maddison (1982) notes) estimates of pre-WWII capital stocks are for the most part more solidly based than are estimates of investment flows. Estimates of changes in capital stocks can thus be constructed with fewer auxilliary assumptions than are required to construct gross investment estimates.

[9]Results reported below were not sensitive to changes in the assumed rate of retirements.

adopted to make the regressions in this section directly comparable to other regressions in this paper. The third was adopted in order to make the relative price structure used to calculate real values correspondmore closely to the average of relative price structures actually found in the sample.

**Figure 2**
**Partial Scatter of Machinery Investment and Growth for the Very Long Run Panel**




The very long-run data base we use here covers seven nations—Canada, Germany (the *Bundesrepublik* after World War II), Italy, Japan, the United Kingdom (including southern Ireland until 1913), and 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.

We divide the past century into periods of roughly fifteen-years, with some of the

division dates offset to match the course of the business cycle and the outbreak of war or the substantial completion of reconstruction. 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.[10]

In choosing among different possible estimates of growth rates and investment shares we stay as close as possible to the estimates compiled by Angus Maddison, whose database has had a substantial influence on conceptions of long-run growth in a comparative perspective. Estimates of output per capita were drawn from Maddison's (1982) *Phases of Capitalist Development*. Estimates of machinery investment were compiled from individual national sources, in most cases once again the same sources used by Maddison.

Figure 2 shows the partial scatter of gross machinery investment and output per worker growth rates for the very long-run panel. Each data point represents the experience of one of the seven nations in the sample for one of the roughly fifteen-year periods into which the century 1870–1980 is divided. The other independent variables in the regression, with their effects held constant in figure 2, are the relative productivity gap vis-a-vis the U.S. at the start of the period, the rate of labor force growth, the rate of gross investment in non-residential construction, and whether a nation was on the losing side in the Second World War.[11]

[10]The fifteen-year frequency of observation was chosen to avoid confusing short-run business cycle fluctuations with long-run shifts in rates of economic growth. If the data were examined year-by-year a substantial proportion of identifying variance would come from business cycle fluctuations. In recessions output drops because productive resources have become slack, not because the reduced pace of investment has significantly reduced the output that could be produced if capacity utilization and employment were at their normal levels. Such business cycle fluctuations would generate an association between investment and growth independent of the links between capital accumulation and long-run full-employment productive capacity.

[11]A First World War loss dummy was dropped after proving insignificant.

**Table 2**
**Growth Regressions for the Very Long Run Panel**

| Independent Variables | Basic Specification | Education Variables | Era Controls | Nation Controls | Both Era and Nation Controls |
|---|---|---|---|---|---|
| Machinery Investment | 0.249 | 0.241 | 0.195 | 0.329 | 0.286 |
| | (0.055) | (0.066) | (0.058) | (0.061) | (0.083) |
| Non-Machinery 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) |
| Log Primary Enrollment/ Population | | -0.014 | | | |
| | | (0.009) | | | |
| Log Secondary Enrollment/ Population | | 0.004 | | | |
| | | (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 |

Table 2 reports regressions for the very long-run panel. Like table 1, table 2 shows a very strong association between machinery investment and growth. The coefficient on machinery investment is approximately the same as in De Long and Summers' (1991) study of the post-WWII era: each one percentage point rise in the machinery investment

share of GDP is associated with a one quarter of one percentage point rise in the annual growth rate of output per worker. This partial association is strong and accounts for a relatively large share of the variation in output per capita growth: a one standard deviation increase in machinery investment is associated with a one-half standard deviation rise in output per worker growth. And the coefficient of the machinery investment variable is precisely estimated, with a t-statistic more than twice as large as any other variable (save the World War II loss dummy).

In addition to the basic specification, table 2 also reports the effects of adding to the list of independent variables estimates of primary and secondary school enrollment rates, era dummies, and nation dummies. Inclusion of the educational enrollment variables has no effect on the machinery investment coefficient, and the educational enrollment variables have little partial association with growth.[12]

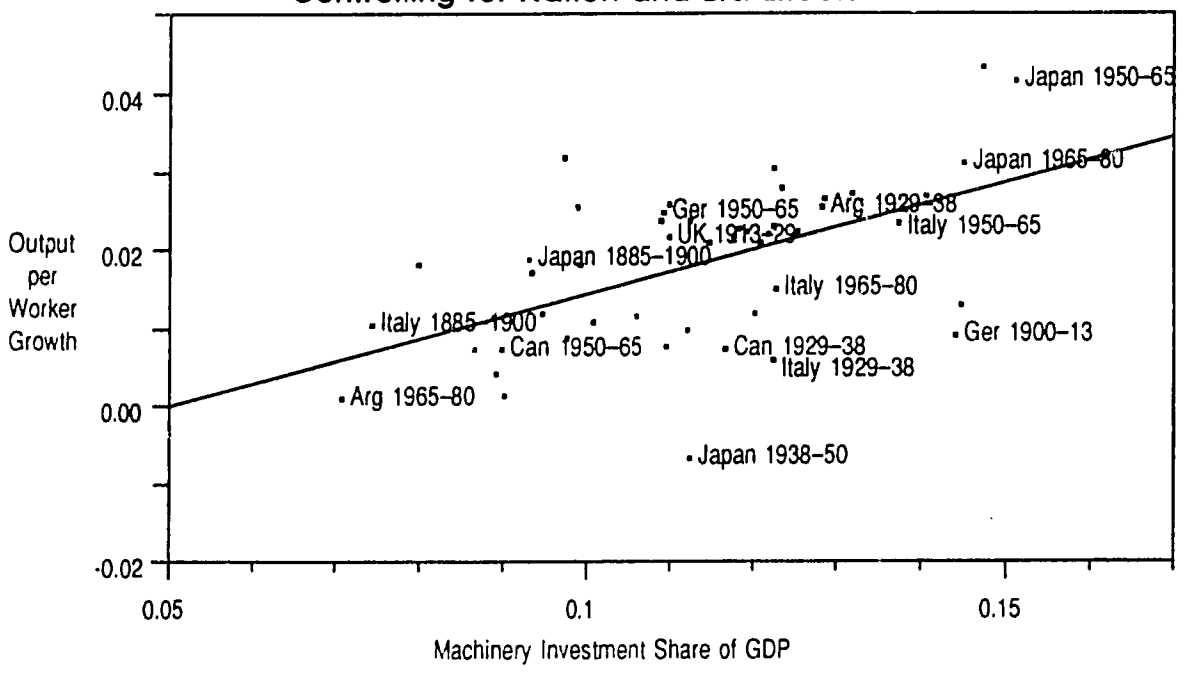
Inclusion of era dummies reduces the machinery investment coefficient by about one-fifth of its magnitude, or one standard error. Inclusion of nation dummies raises it by one and a half standard errors. Only one of the era dummy variables—that for 1929–38—is significantly different from zero. Only two of the nation dummy variables—Argentina and Japan— are significant, with Argentina low and Japan high. Thus there is no strong evidence that important nation- or era-specific effects have been omitted from the independent variables and are thus biasing the results.

Figure 3 shows the partial scatter of machinery investment and growth controlling for nation and era effects. The variations in machinery investment shown on the horizontal and growth rates shown on the vertical axis are those portions orthogonal not only to labor force growth, non-machinery investment, and relative backwardness, but also to nation- and era-specific average growth rates. For example, post-WWII

[12]This does not necessarily imply that human capital accumulation is unimportant for growth. It more likely means only that estimates of enrollment rates are bad measures of human capital accumulation.

Argentina is in the lower left hand quarter of figure 3 but not of figure 2. Post-WWII Argentinian growth has been slow and machinery investment low not so much in absolute terms as relative to the (high) post-World War II average rates of growth and investment in the economies in the panel.

**Figure 3**
**Partial Scatter of Machinery Investment and Growth for the Very Long Run Panel, Controlling for Nation and Era Effects**




Nevertheless, the differences between figures 2 and 3 are not of overwhelming importance. Controlling for nation- and era-specific factors does not greatly distort the pattern of identifying variance, and the partial scatter in figure 3 appears largely similar to the partial scatter in figure 2. This should not come as a surprise: it is implicit in the relatively small sizes and low significance levels of the nation- and era-specific dummy variables

*Backcasts: 1950–1960*

Yet another potential source of information about the growth-machinery nexus is the comparative performance of economies in the 1950's before the beginning of the De Long and Summers (1991) sample. We have constructed estimates of machinery investment rates in the 1950's for 54 countries. As always, we omit high-income oil-exporting nations and centrally-planned economies from our sample. For the OECD nations, estimates of machinery investment in the 1950's are derived from the official OECD estimates of the current-price machinery investment share, adjusted to international dollars.

For other nations our estimates of machinery investment in the 1950's were constructed by multiplying Summers and Heston's (1991) estimates of investment shares in the 1950's by our own estimates of the machinery investment share of total investment calculated for the previous subsection. 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 do contain substantial amounts of information about the division of investment between categories in the 1950's. We report regressions both for the sample of all 54 nations and for the OECD alone.

Figure 4 plots the partial scatter of growth and machinery investment in the 1950's. Table 3 presents regressions covering the 1950's for various modifications of our basic specification and sample. The decade of the 1950's is a period only forty percent as long as that covered by the basic 1960–85 regressions of De Long and Summers (1991). As a result of the shortness of the sample, we are not surprised that the standard errors of the

regression and the coefficients are relatively large. But note that the magnitude of the machinery investment coefficient: it is almost exactly the same as for the 1960–85 sample (although it is not very precisely estimated). Figure 4 and table 3 show that the growth-machinery nexus is as strong in the 1950's as over 1960–85.

**Figure 4**
**Partial Scatter of Growth and Machinery Investment in the 1950's**

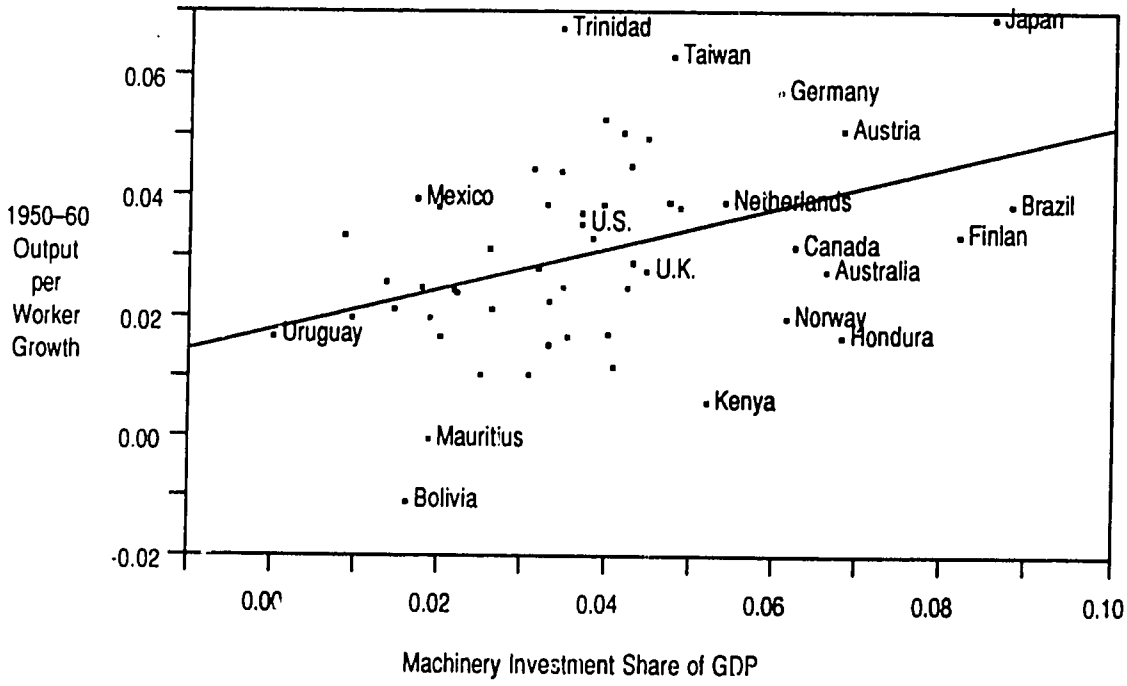



Figure 4 shows that the high growth-high machinery countries in the 1950's were a slightly different set than they were later on. In the 1950's Germany especially is a high growth-high machinery investment country. Brazil—which is a moderate investment-high growth country in many of our regressions covering the 1960–85 period—is as a high investment-moderate growth country in the 1950's. The 1950's are a somewhat different "natural experiment," possessing a somewhat different pattern of variation in

machinery investment than found in subsequent post-World War II years.

**Table 3**
**Growth Regressions for the 1950's**

| Independent Variables | Basic Specification | OECD Nations Only | High-Pdty[14] Economies Only | Basic with[13] Schooling Variables | Basic with Continent Dummies |
|---|---|---|---|---|---|
| Machinery Investment | 0.332 | 0.218 | 0.384 | 0.260 | 0.274 |
| | (0.109) | (0.130) | (0.122) | (0.126) | (0.111) |
| Non-Machinery Investment | 0.020 | -0.013 | 0.027 | 0.008 | -0.001 |
| | (0.047) | (0.066) | (0.075) | (0.049) | 0.047 |
| Pdty Gap vis-a-vis US | 0.035 | 0.061 | 0.065 | 0.048 | 0.043 |
| | (0.011) | (0.010) | (0.013) | (0.014) | (0.013) |
| Labor Force Growth | -0.338 | 0.272 | 0.083 | -0.107 | 0.152 |
| | (0.212) | (0.240) | (0.233) | (0.247) | (0.335) |
| Primary School Enrollment | | | | 0.020 | |
| | | | | (0.011) | |
| Secondary School Enrollment | | | | 0.012 | |
| | | | | (0.019) | |
| $R^2$ | 0.338 | 0.721 | 0.595 | 0.398 | 0.493 |
| SEE | 0.0154 | 0.0092 | 0.0129 | 0.0150 | 0.0142 |
| n | 54 | 20 | 28 | 54 | 54 |

The first two columns of table 3 report regressions for all 54 nations and for just the OECD nations. The association of machinery and growth is somewhat weaker in the OECD sample. To some degree this may arise because of the endogeneity of OECD membership: Australia, Japan, and New Zealand joined the group in the early 1960's. It seems reasonable to suppose that had rich South American nations like Uruguay and

[13]Enrollment rates as a fraction of the school-age population in 1960.

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

Argentina not stagnated during the 1950's they would have joined as well. If the possession by Uruguay, Argentina, and Chile of low machinery investment shares and low growth rates in the 1950's excluded them from the OECD sample, it is not surprising that the OECD sample does not show as strong a relationship between machinery investment and economic growth.

Some evidence supporting this hypothesis is contained in the third column of table 3. It shows that the machinery investment coefficient estimated for the 1950's is very large when the sample is selected not by OECD membership but by initial 1950 levels of output per worker.

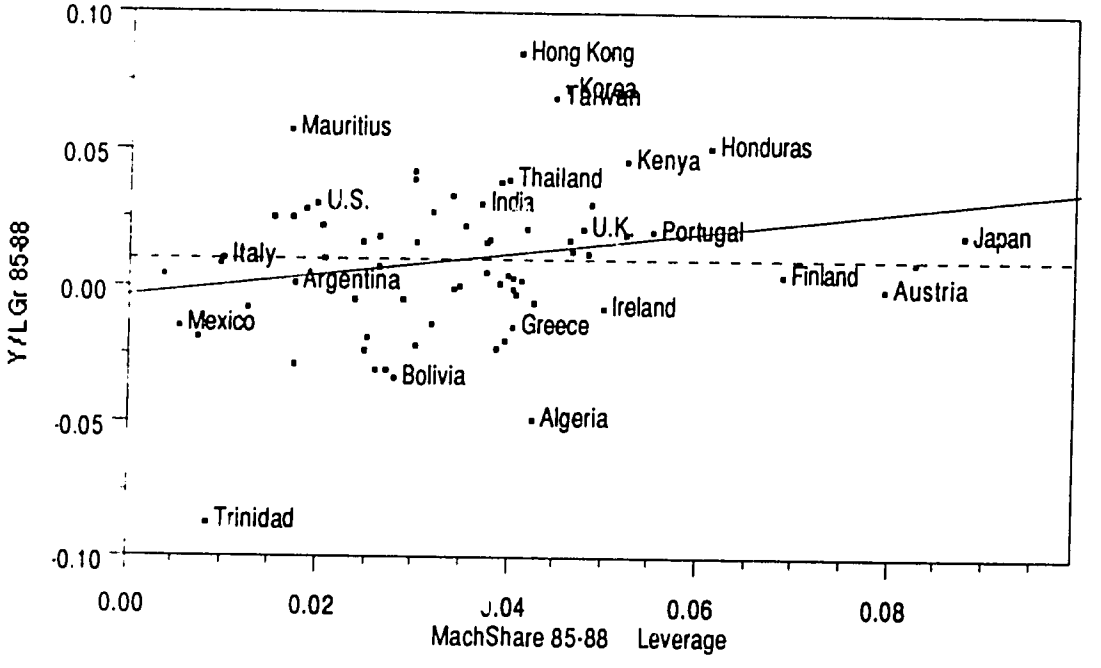
The fourth and fifth columns of table 3 show that the inclusion of some additional variables—inthis case school enrollment rates and continent dummies—does not have a large effect on the estimated machinery investment coefficient. As in De Long and Summers (1991),the association between machinery investment and growth does not appear to be the result of the omission of human capital formation variables, or of fixed continent-specific factors.

*Forecasts: 1985–1989*

Relatively few years have elapsed since the 1985 end of the sample period used in De Long and Summers (1991). It would be somewhat surprising if we were able to precisely estimate the relationship between growth and machinery for such a short period. As Easterly *et al.* (1992) have pointed out, there is enormous temporary year-to-year variation in cross-country growth rates that has a variance approximately twelve times as great as the cross-country variance in trend growth rates. Thus the share of growth rate variance that we could ever hope to explain in a cross-country regression

over a five year period is much smaller than the share of variance we could hope to explain over a longer sample period like that of De Long and Summers (1991). Moreover, the high residual variance implies that coefficients will almost surely be imprecisely estimated.

**Figure 5**
**Partial Scatter of Growth and Machinery Investment 1985–89**




Nevertheless, figure 5 and table 4 report regressions for the very short 1985–89 period with a sample of seventy-one economies. For the OECDnations the estimates of machinery investment shares are derived from official OECD year-to-year estimates of national product adjusted to the 1985 ICP benchmark. For other nations in the De Long

and Summers (1991) sample the share of machinery in total investment over 1985–89 was set equal to the ratio in the 1985 ICP benchmark year.[15] Thus for non-OECD nations the estimated machinery investment rates over the 1985–89 period are of low quality.

**Table 4**
**Growth Regressions for the 1985–89 Period**

| Independent Variables | Basic Specification | OECD Nations Only | High-Pdty[16] Economies Only | Basic with Continent Dummies |
|---|---|---|---|---|
| Machinery Investment | 0.391 | 0.096 | 0.261 | 0.248 |
| | (0.199) | (0.167) | (0.275) | (0.201) |
| Non-Machinery Investment | 0.113 | 0.061 | 0.075 | 0.081 |
| | (0.072) | (0.140) | (0.119) | (0.073) |
| Pdty Gap vis-a-vis US | 0.058 | 0.015 | 0.078 | 0.040 |
| | (0.025) | (0.020) | (0.039) | (0.026) |
| Labor Force Growth | -1.512 | -0.107 | -2.087 | -1.941 |
| | (0.432) | (0.670) | (0.584) | (0.508) |
| $R^2$ | 0.296 | 0.075 | 0.317 | 0.426 |
| SEE | 0.0282 | 0.0141 | 0.0319 | 0.0264 |
| n | 71 | 20 | 38 | 71 |

The results in table 4 show that in trying to estimate the association of machinery and growth over 1985–89, we have pushed beyond the limits of the questions that the data can effectively answer. In the first column of table 4 the machinery investment coefficient is in its standard range—0.391. But it is very imprecisely estimated. Its 0.95

[15]For nations outside the De Long and Summers (1991) sample, the share of machinery in total investment over 1985–89 was imputed from proxy variables as described for the sample of "additional nations" in section IV below.

[16]Economies with 1950 output per worker levels at least one-quarter that of the United States.

confidence interval ranges from -0.007 to 0.789. For the OECD sample the machinery investment coefficient is not of high magnitude. And for the other regressions in table 4 the standard errors are even higher than in table 1.

Figure 5 shows why the machinery investment coefficient is so imprecisely estimated. The residual variance of 1985–89 growth rates is enormous, with a standard deviation of 2.8 percent per year. With such a high residual variance, it is surprising that the data speak as strongly as they do in support of the growth-machinery connection. The regression results in table 4 and the scatter in figure 5 are welcome confirmation of their opinions to those who already believe that there is a strong growth-machinery nexus. But they would be entirely unconvincing to any who were even slightly skeptical.

## IV. The Growth-Machinery Nexus: Evidence from Additional Nations

Our original study covered a sample of some sixty-odd economies that had been at some point or other closely studied by the U.N. International Comparison Project. The ICP had constructed estimates of national relative price and quantity structures for specific benchmark years denominated in a common "international dollar" unit. The ICP allowed for cross-national comparisons orders of magnitude more accurate than any made before (see Kravis, Heston, and Summers, 1982). We used estimates of the share of total investment devoted to machinery equipment derived from the benchmark-year data of Kravis, Heston, and Summers (1982) and of other versions of the ICP to estimate the share of machinery investment in GDP over 1960–85, and merged our machinery investment estimates with the cross-country comparative

national growth accounts of Summers and Heston (1988, 1991).

As we pointed out in De Long and Summers (1991), these estimates we used are not especially good estimates of machinery investment. They depend heavily on the ratio of machinery to total investment in the benchmark years being a good proxy for the average ratio of machinery to total investment. Moreover, these estimates are confined to those economies that served as benchmarks in the ICP.

*Extending the Sample*

Alternative ways of estimating real rates of machinery investment allow us to construct estimates for economies not included in the sample of De Long and Summers (1991). There are many variables that could serve as proxies for the extent of an economy's machinery investment effort. As Warner (1991) has demonstrated, the bulk of machinery and equpment are imported from abroad in all except the very richest economies. Trade statistics are thus a fruitful source of data on machinery investment. As De Long and Summers (1991) showed, the relative price of machinery and equipment has a high correlation with the rate of machinery investment. For economies for which direct machinery investment data are lacking, data on price structures can help impute machinery investment estimates.

Aitken (1991) has constructed estimates of the relative price of machinery in the 1980's. Lee (1992) has compiled estimates of real machinery and equipment imports over 1960–85. Our strategy in this subsection is to use these correlates of machinery investment to construct machinery investment estimates for economies not in the sample of De Long and Summers (1991), and to show that the regressions we reported

hold true for out-of-sample data.

**Table 5**
**Machinery Investment Rates as a Function of Capital Goods Imports, Tariff Structures, and Relative Prices**

| Sample | Excludes G-7 | Excludes G-7 | Excludes G-7 | Includes G-7 |
|---|---|---|---|---|
| Investment Share of GDP | 0.0979<br>(0.0359) | 0.0978<br>(0.0321) | 0.0794<br>(0.0470) | 0.1394<br>(0.0461) |
| Productivity Gap vis-a-vis U.S. | 0.0242<br>(0.0158) | 0.0330<br>(0.0130) | 0.0257<br>(0.0191) | -0.0251<br>(0.0174) |
| Aitken Estimates of Machinery Prices | -0.1473<br>(0.0978) | | -0.1256<br>(0.1079) | -0.3157<br>(0.1289) |
| Imports of Machinery as a Share of GDP | 0.8357<br>(0.1681) | 0.9167<br>(0.1351) | 0.9804<br>(0.2579) | 0.1674<br>(0.2058) |
| 1980's Tariffs on Machinery | | | 0.0049<br>(0.0094) | |
| $R^2$ | 0.744 | 0.745 | 0.656 | 0.647 |
| SEE | 0.0108 | 0.0105 | 0.0115 | 0.0163 |
| n | 34 | 39 | 29 | 40 |

Table 5 reports regressions of machinery and equipment investment rates over 1960–85, as estimated in De Long and Summers (1991), on proxies for the investment effort devoted to machinery. The sample in the first three columns of table 5 excludes the machinery-exporting economies of the G-7. The sample also excludes the African outliers Tanzania, Zambia, and Zimbabwe, which De Long and Summers (1991) estimated to have high shares of machinery investment in GDP, yet which have no capital goods producing sectors and import only small quantities of machinery from the industrial core.[17] We omit these nations as well as the G-7 nations from the sample

used in determining the relationship between machinery investment rates and the available proxies for machinery investment effort.

As table 5 shows, nearly three quarters of the variation in machinery investment can be predicted from these proxies for machinery investment effort. Of the proxies the best predictor is the share of machinery imports in GDP. It is a direct "output" proxy, while the other proxy variables are more estimates of machinery investment "effort." In the table 5 regressions, the most significant positive outlier of the economies in the De Long and Summers (1991) sample is Brazil, which has a regression residual more than twice as large as any other positive residual. According to Lee (1992), Brazil imported only 0.8 percent of GDP in machinery investment on average over 1960–85. Yet the ICP benchmarks of Brazil's machinery share of investment and Brazil's high general investment share of GDP led us to estimate 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. Thus we are not greatly disturbed by the inability of our proxies to account for machinery investment in Brazil.

**Table 6**

[1]We believe that our previous estimates of their rates of machinery investment are overstated, perhaps because of our failure to note that the benchmark year we were using was also a peak year in the construction of the Chinese-built Tanzania-Zambia railroad.

## Machinery Investment and Growth Over 1960–85 for Economies Not in the Sample of De Long and Summers (1991)

| Independent Variables | Basic Specification | Including Schooling Variables | Including Continent Dummies | Including Barro Variables |
|---|---|---|---|---|
| Machinery Investment | 0.350<br>(0.116) | 0.264<br>(0.123) | 0.244<br>(0.129) | 0.243<br>(0.099) |
| Non-Machinery Investment | 0.072<br>(0.062) | 0.048<br>(0.062) | 0.060<br>(0.082) | 0.021<br>(0.050) |
| Pdty Gap vis-a-vis US | 0.038<br>(0.025) | 0.067<br>(0.029) | 0.026<br>(0.032) | 0.062<br>(0.024) |
| Labor Force Growth | -0.217<br>(0.444) | -0.089<br>(0.506) | -0.190<br>(0.593) | -0.162<br>(0.397) |
| $R^2$ | 0.450 | 0.526 | 0.569 | 0.761 |
| SEE | 0.0144 | 0.0141 | 0.0145 | 0.0108 |
| n | 27 | 27 | 27 | 27 |

Using the first regression equation in table 5, we impute estimates of 1960–85 machinery investment rates for 27 economies not included in the original De Long and Summers (1991) sample. Table 6 reports results from our basic specifications over the 1960–85 period, using as our sample only those economies not included in the De Long and Summers (1991) database. Even though the sample is a small one, the machinery investment coefficient remains reasonably precisely estimated. Moreover, it remains in the high range seen in the other regressions. And once again the estimated machinery investment coefficient is little affected by the inclusion of continent dummies, of rates of schooling, or of Barro's collection of five political and educational variables.

**Figure 6**

**Partial Scatter of Growth and Machinery for Economies Not In De Long-Summers (1991) Sample**

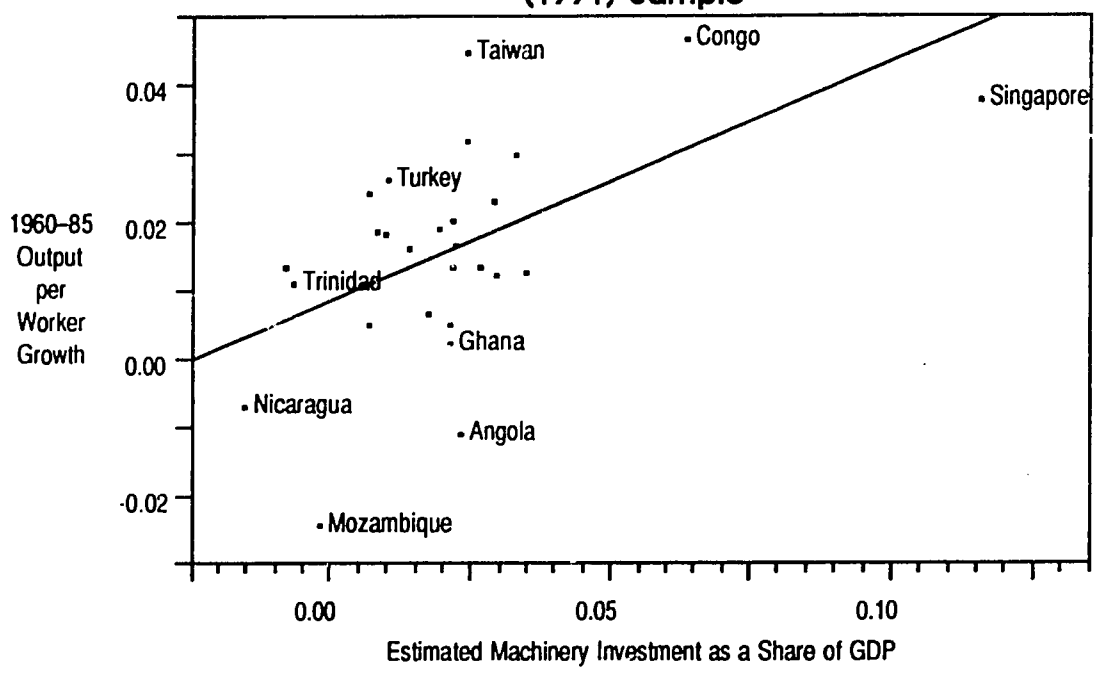



Figure 6 reports the partial scatter of growth and machinery investment in the regression underlying the first column of table 6. Figure 6 shows that the sample of the additional economies contains one extreme observation: Singapore. But the large and significant estimated machinery investment coefficient is not a product of the inclusion of Singapore in the sample. Indeed, the inclusion of Singapore significantly lowers the estimated machinery investment coefficient. The presence of Singapore in the sample does markedly increase the precision of the estimates. If Singapore were excluded from the sample, the standard errors in table 6 would be approximately twice as large.

Angola and Mozambique possess extremely large negative residuals. They are poor countries that have undergone long and bloody civil wars with U.S. and South African-backed guerrilla movements. They have also attempted—like other African countries such as Zimbabwe—to introduce large elements of central planning and

socialist production into their economies. These factors seem to us more than enough to account for their disappointing growth rates.

Taiwan possesses an extremely large positive residual in figure 6: nearly three percentage points per year of growth faster than predicted from the regression equation in column one of table 6. Machinery investment and the other basic variables in De Long and Summers (1991) do not account for more than four-ninths of growth rate variation. Adding Barro's (1991) politico-economic and education variables to the list of growth-causing factors accounts for another thirty percent of the growth rate variance, but does not help account for the rapid growth of Taiwan.

Given the large magnitude of the residuals that remain, and the small size of the sample of additional nations, it is striking that the regressions are as consistent with those of De Long and Summers (1991) as they are. The sample of economies analyzed in this subsection—a sample relying exclusively on new data, including only economies not analyzed in our original De Long and Summers (1991)—shows the same pattern as did our earlier work. Machinery investment is strongly associated with output per worker growth. Machinery invsetment by itself accounts for a large share of growth rate variation. And machinery investment has a much larger association with growth than other forms of investment.

*Maximum 1960–85 Cross Section Regression*

To summarize the evidence on the strength of the association of machinery and growth in the 1960–85 period, it is worth combining all of the sources of data on machinery investment and estimating the regression of output per worker growth on machinery investment for the maximum cross-section sample.[18] Table 7 reports such

regressions, and figure 7 reports the partial scatter of growth and machinery investment.

As would be expected, the results estimated in figure 7 and table 7 are somewhat stronger than those estimated by De Long and Summers (1991). The t-statistic on the machinery investment variable is 7.09 in the first column of table 7, but only 4.07 in the analogous regression in De Long and Summers (1991). In the maximum cross-section the regression accounts for 45 percent of the variation in output per worker growth rates, as opposed to 29 percent in the sixty-odd nation sample of De Long and Summers (1991).

**Table 7**
**Machinery Investment and Growth Over 1960–85 for the Maximum Cross Section**

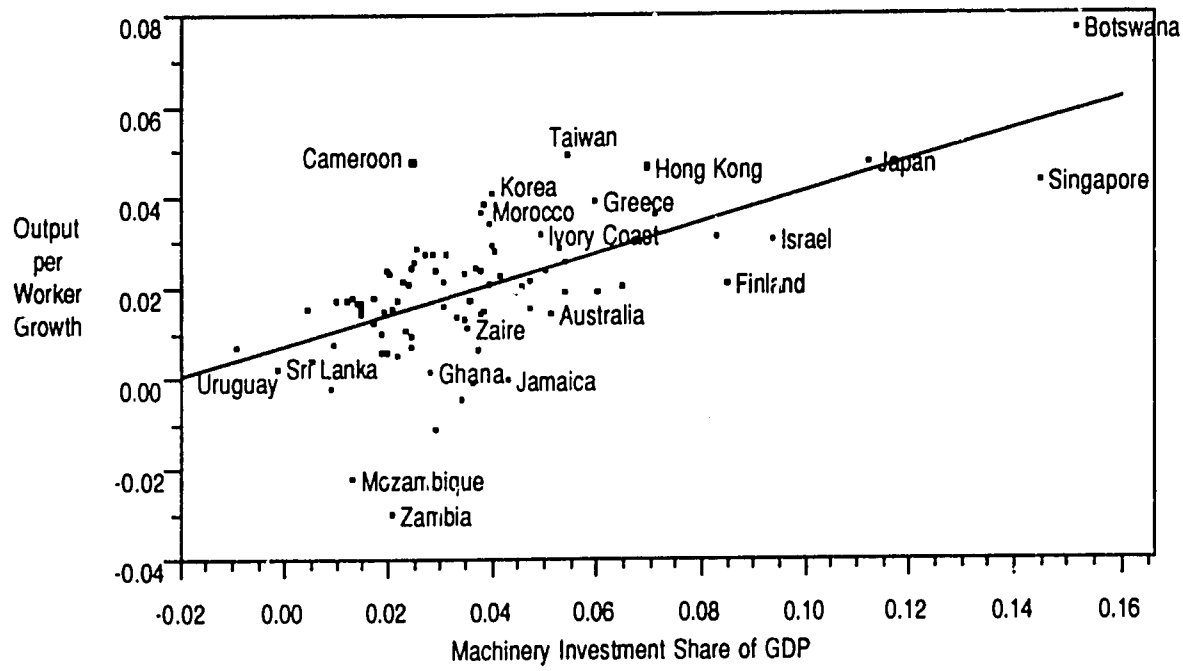
| Independent Variables | Basic Specification | Schooling Variables | Continent Dummies | Barro Variables |
|---|---|---|---|---|
| Machinery Investment | 0.342 | 0.318 | 0.302 | 0.293 |
| | (0.049) | (0.055) | (0.053) | (0.054) |
| Non-Machinery Investment | 0.048 | 0.020 | 0.014 | 0.020 |
| | (0.028) | (0.029) | (0.032) | (0.028) |
| Pdty Gap vis-a-vis US | 0.032 | 0.043 | 0.033 | 0.050 |
| | (0.008) | (0.010) | (0.010) | (0.010) |
| Labor Force Growth | 0.018 | 0.015 | 0.091 | 0.013 |

[18]Machinery investment data underlying figure 7 and table 7 come from three sources. For OECD nations, the estimates of machinery investment over 1960–85 are those underlying figure 10 and equation 4, calculated by taking year-by-year OECD estimates of machinery investment shares of national product and deflating them to 1985 international dollars. For the additional nations not included in the De Long and Summers (1991) sample—and for Tanzania, Zambia, and Zimbabwe, for which the volumes of machinery imports are grossly inconsistent with previous calculations of machinery investment rates—the estimates of machinery investment over 1960–85 are those imputed from the proxies for machinery investment effort. For other non-OECD nations included in the De Long and Summers (1991) sample, the estimates of machinery investment are averages of the values imputed from the proxies and the original De Long and Summers estimates.

| | | | | |
|---|---|---|---|---|
| | (0.161) | (0.178) | (0.227) | (0.171) |
| $R^2$ | 0.464 | 0.486 | 0.497 | 0.553 |
| SEE | 0.0126 | 0.0123 | 0.0124 | 0.0117 |
| n | 89 | 88 | 88 | 88 |

Significant variation in output per worker growth rates remains unaccounted for. The maximum share of growth rate variance accounted for in the regressions of table 7 is fifty-six percent. Many observations continue to show large residuals, as figure 7 displays. A number of the outliers with negative residuals are a number of sub-Saharan African nations with semi-socialized economies: Angola, Madagascar, Mozambique, Zaire, and Zambia. A number of the economies that show large negative residuals—Angola, Mozambique, and Nicaragua—have suffered through long and destructive civil wars.

**Figure 7**
**Partial Scatter of 1960–85 Growth and Machinery Investment for the Maximum Extended Cross Section**




Prominent among the positive residuals are some of the most rapidly growing East Asian economies—Hong Kong, Korea, and Taiwan—in addition to countries like Morocco, the Cameroon, the Congo, and most prominently Botswana in Africa. A high rate of machinery investment is not the sole determinant of rapid growth. Indeed, some of the East Asian economies now put forward as models for rapid development do not display extraordinarily high rates of machinery investment, although some—Japan and Singapore, and to a lesser extent Hong Kong—do.

Young (1992) has argued on the basis of a comparison of growth in Hong Kong and Singapore that physical capital accumulation—including machinery investment—is relatively unimportant in growth compared to human capital accumulation as measured by formal education.[19] From figure 7 it is clear how he could reach such a

[19]Some of Young's claims are surely rhetorical exaggerations. His belief that Singapore has experienced *no* total factor productivity growth since 1960 has asits corollary (through the dual) that the real wages of

conclusion: the line connecting Hong Kong and Singapore is flat, suggesting that Singapore has not received significant benefits from its very high machinery investment rate. But figure 7 also provides very good reason for disregarding conclusions about general patterns of growth and development based on the drawing of a line between just these two points. A line connecting the points Hong Kong and Singapore has nothing to do with the slope of regression lines capturing the general cross-economy pattern of growth and development.

All of the samples and eras considered in this and the previous section carry the same message. In all cases regressions using new data strongly confirm our previous claim that the growth-machinery nexus is strong and robust. The very long run panel data set, the cross-section regression covering the 1950's alone, the weak results for the 1985–89 period, and the regression using as its sample the 27 additional nations all use databases that have no overlap with that of De Long and Summers (1991). If our earlier conclusions were due to some specific peculiarity or feature of our previous data, then these tests of our hypotheses should have revealed their fragility. Our own confidence that the correlations set out in De Long and Summers (1991) are in fact robust features of industrialization has been greatly strengthened by the extra data we have presented in this and the previous section.

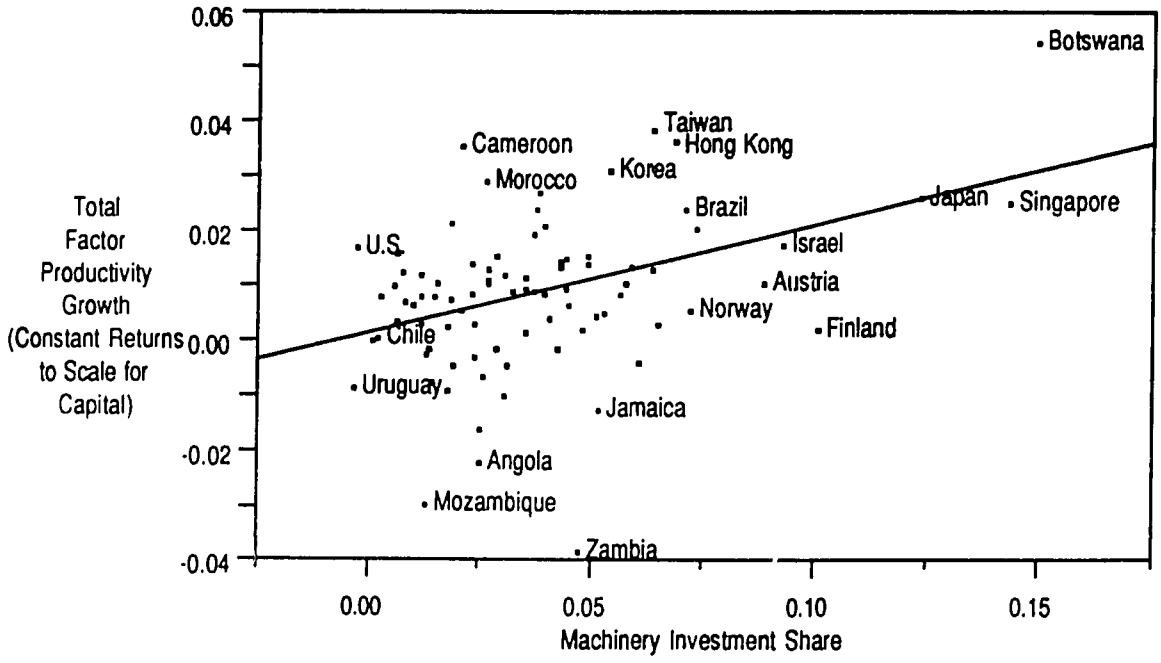
## V. Interpretation

*Productivity: Is the Growth-Machinery Correlation the "Normal" Return to Investment?*

unskilled workers,the real wages of workers with a fixed educational level, and real land rents in Singapore today are at the levels of 1960 as well.

The partial association of machinery investment and growth is, of course, much stronger than one would expect under the assumption that the private returns to factors of production are equal to their social marginal products. This shows itself as a strong correlation between machinery investment and total factor productivity growth. Figures 8 and 9 plot partial scatters of two different estimates of total factor productivity growth and machinery invesment. Equations 1 and 2 beneath the figures report regressions of the estimates of total factor productivity growth on machinery investment and on the productivity gap vis-a-vis the U.S.

**Figure 8**
**Partial Scatter of Total Factor Productivity Growth and Machinery Investment, 1960–1985**

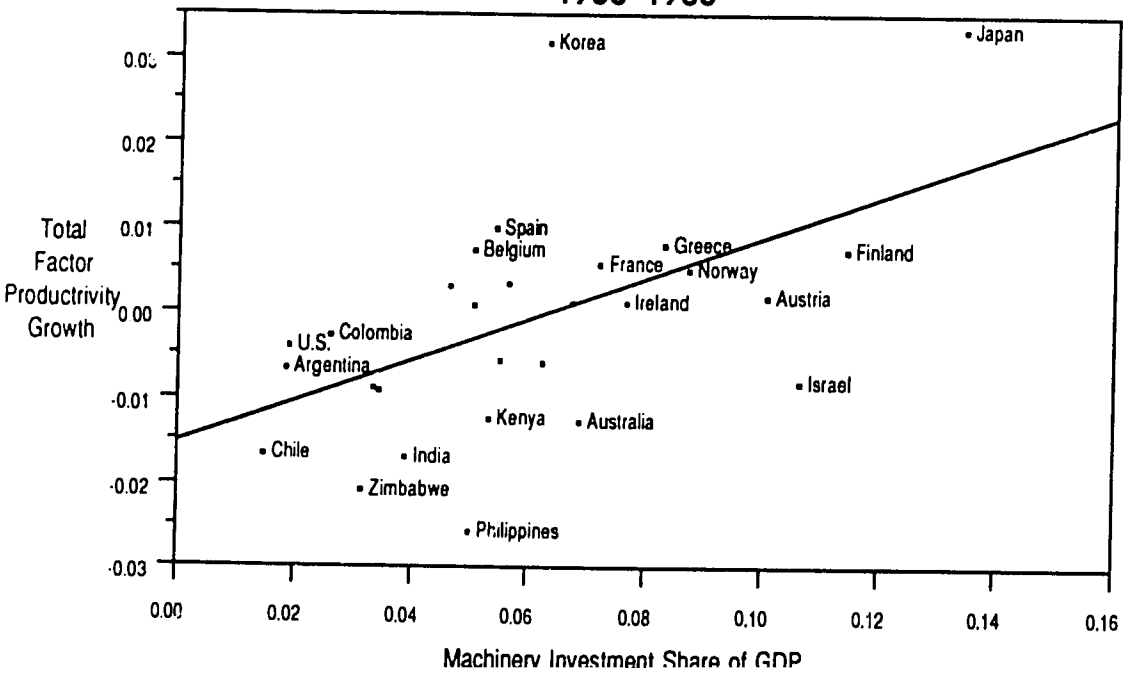



(1) GDP/Wkr Gr= +0.039(Rel. GDP Gap) +0.198(Mach Inv)
(0.008) (0.048)

n = 88 $R^2$=.235 SEE=.0130

Figure 9 allows for diminishing returns to capital by assuming a Cobb-Douglas production function, with the coefficient on capital adjusted to yield an average profit rate of twelve percent, and uses Summers and Heston (1991) estimates of capital-output ratios to calculate the variation in profit rates across countries. Because of the limited number of nations for which Summers and Heston make capital stock estimates, the sample is relatively small: twenty-nine nations.

**Figure 9**
**Partial Scatter of Total Factor Productivity Growth and Machinery Investment, 1960–1985**




(2) GDP/Wkr Gr= +0.027(Rel. GDP Gap) +0.240(Mach Inv)
(0.011) (0.073)

n = 29 R2=.312 SEE=.0114

According to both sets of total factor productivity estimates, a large productivity gap does provide significant opportunities for total factor productivity growth through "catch-up."[20] According to equation 1, a country that in 1960 had an output per worker level one-third that of the U.S. would have closed almost half of the gap by 1985 had it managed to achieve the same rate of machinery investment and residual factors as the U.S.

But the more important feature of figures 8 and 9 is that a high rate of machinery investment is associated with very rapid total factor productivity growth. Over a twenty-five year period, a country devoting one additional percentage point of GDP per year to machinery investment raises relative output per capita at the end not only by the direct growth-accounting effect of a higher capital stock— a cumulative matter of 2.5 percent—but also by the association of machinery investment with total factor productivity growth—a matter of an additional 5 percent. Such total factor productivity gains are *not* realized by economies that devote resources to non-machinery investment.

Similar conclusions follow from estimates of the level of output per worker today as a function of the machinery and non-machinery capital stocks. Table 8 reports regressions for a twenty-nine country sample, using data from Summers and Heston (1991), of output per worker *levels* on stocks of machinery and equipment capital per worker, of non-residential structures capital per worker, and on the secondary school enrollment rate. All variables are normalized so that the United States in 1985 is equal to

[20]Regressions including education rates, labor force growth rates, and non-machinery investment rates as possible determinants of productivity growth did not produce significant differences.

one.

In the first column the level of output per worker is regressed on all three of the three independent variables, which together account for eighty-five percent of the variation in output per worker.[21] Of these three, the stock of machinery investment per worker is by far the most closely associated with the level of output per worker.

**Table 8**
**1985 Output per Worker Levels as a Function of Machinery Capital Stocks**

| | | | | |
|---|---|---|---|---|
| Machinery Capital Stock | 0.466<br>(0.103) | 0.510<br>(0.098) | 0.492<br>(0.077) | 0.460<br>(0.108) |
| Structures Capital Stock | 0.031<br>(0.081) | 0.067<br>(0.077) | | 0.029<br>(0.083) |
| Secondary School Enrollment Rate | 0.177<br>(0.139) | | 0.120<br>(0.128) | 0.191<br>(0.150) |
| Primary School Enrollment Rate | | | | -0.063<br>(0.228) |
| $R^2$ | 0.852 | 0.843 | 0.852 | 0.853 |
| SEE | 0.111 | 0.113 | 0.110 | 0.114 |
| n | 29 | 29 | 29 | 29 |

An increase in the machinery capital stock per worker of one percentage point of the U.S. level carries with it an increase in output per worker of 0.47 percentage points of the U.S. level.The U.S. machinery stock per worker has been approximately one-third of output per worker, and so a one dollar difference across countries in machinery capital per worker is associated with a $1.50 difference in gross output per worker. This is far greater than growth-accounting calculations would suggest: even with a fifteen

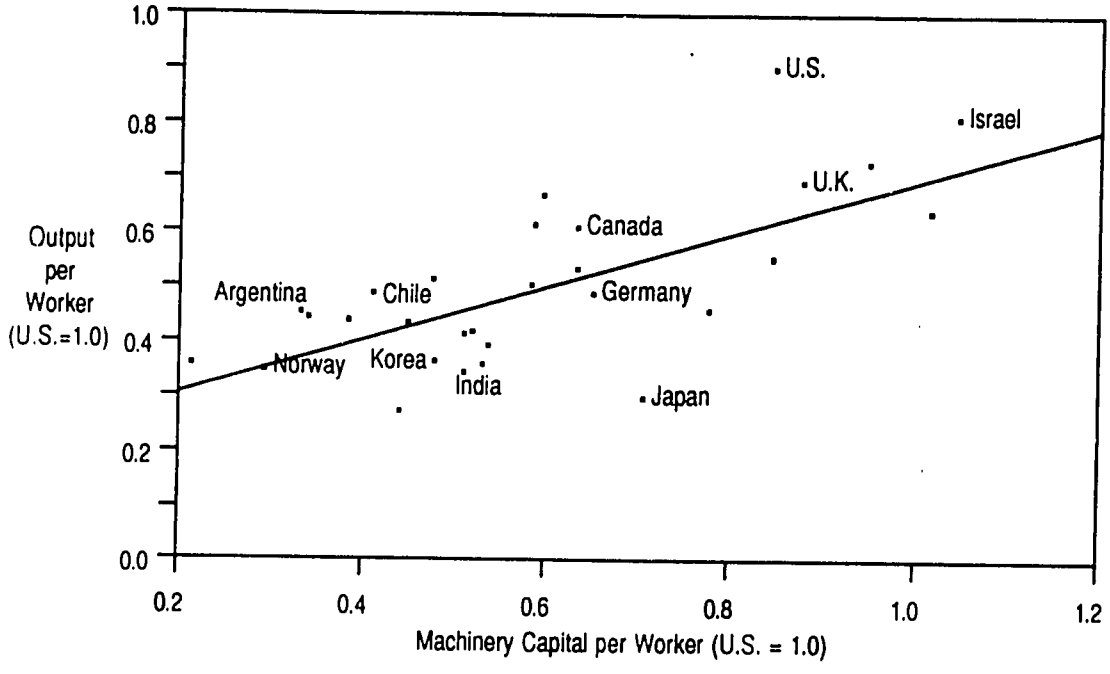
[21]Residuals are not heteroskedastic: there is no evidence that they are an increasing function of scale.

percent net rate of return on capital and a ten percent depreciation rate on machinery, a given dollar of machinery capital contributes capital services of only $0.25 to the economy, only one sixth as much as the regression coefficients in table 8.

The structures capital stock has no significant association with output per worker levels. Education variables are positively related to output per worker variables, but their effects are not precisely estimated, and are an order of magnitude smaller than the association of machinery capital stocks and output per worker levels. The other columns of table 8 show that omitting variables, or including an extra education variable does not markedly affect the partial association of the machinery capital stock and the output per worker level.

The point-by-point information about the partial association is shown in figure 10, which displays the partial scatter of output per worker levels and machinery capital stocks. Interestingly, Japan is not an especially influential observation in this partial scatter. Relative to its levels of school enrollment, it has not a high but a moderate level of output per worker. And relative to its levels of school enrollment, Japan fails to have a high and in fact has a relatively low machinery capital stock per worker. The influential observations in figure 10 are economies like that of the U.S., Israel, and the U.K. in the first, and Argentina, India, and Korea in the third quadrant.

**Figure 10**
**Partial Scatter of Output per Worker *Level* and Machinery Capital Stock per Worker**



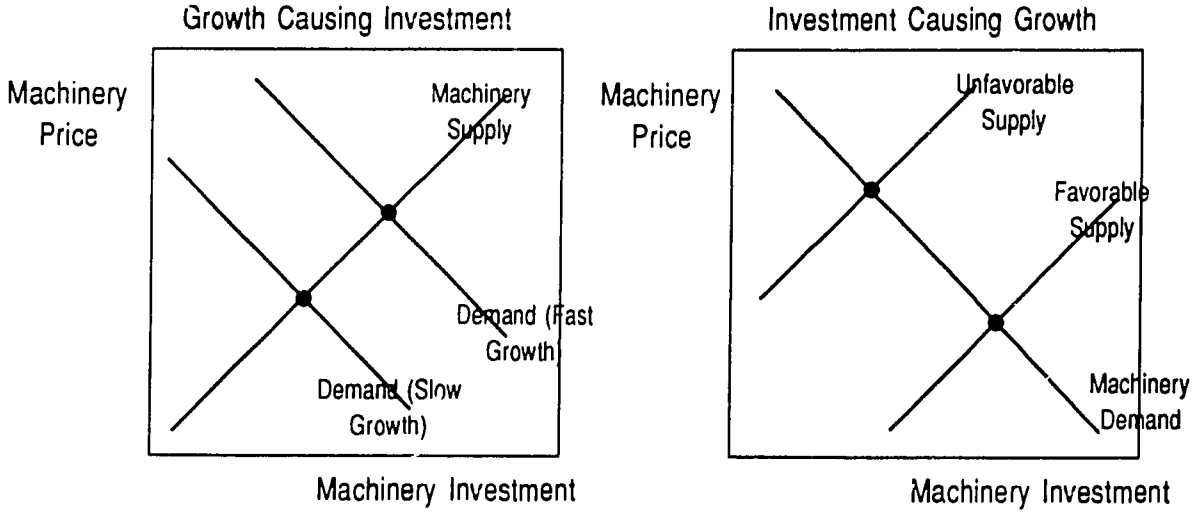

The association between machinery stocks and output per worker levels would not convince any skeptics that machinery is a key factor in economic growth. Skeptics will point to the very large size of the estimated correlation: $1.00 extra in machinery capital per worker buys you $1.50 extra in output per worker. There is a more than even chance that this correlation arises because of feedback: rich countries invest more in dollar terms than do poor countries, and have higher capital stocks. It is hard to think of *any* model of economic growth in which there is not a rough one-for-one proportional association of productivity levels with capital stocks. Nevertheless, it is noteworthy that the weight in this roughly proportional association is entirely on the machinery stock, and not at all on the structures capital stock per worker.

*Causality*

Does the strong growth-machinery nexus mean that machinery investment causes rapid growth, or that rapid growth induces high machinery investment? In De Long and Summers (1991), we have argued that machinery investment was the cause and growth the effect. Here we attempt to strengthen the case for interpreting the growth-machinery nexus as a causal link.

The most powerful piece of evidence presented in De Long and Summers (1991) for attributing causal significance to the machinery-growth nexus was the strong *negative* association between machinery prices on the one hand and machinery investment and growth on the other. If high rates of investment were a consequence rather than a cause of growth, one would expect the price of machinery to be high in rapidly-growing countries because of strong demand pressing on the limits of available supply.

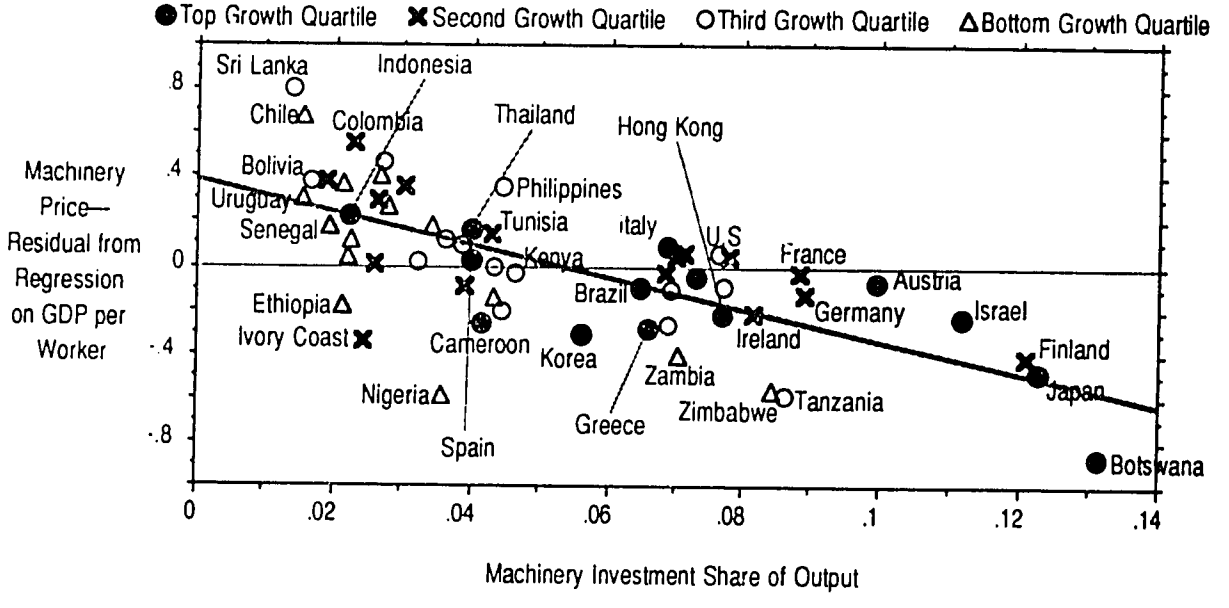
**Figure 11**
**Identification from the Correlation of Machinery Prices and Quantities**




This argument is simple supply-and-demand. Fast growth could increase

machinery investment by raising profits and shifting the derived demand for machinery investment to the right. This would move the economy upward and outward along a machinery supply curve, as shown in the first panel of figure 11. In such a case, we would see rapid growth go together with high machinery investment and relatively high machinery prices.

**Figure 12**
**Machinery Prices, Machinery Investment, and Output Growth**




In fact, rapid growth turned out to be associated with low relative machinery prices. Figure 12 shows relative machinery prices, relative machinery investment rates,and GDP per worker growth rates for the dataset used in De Long and Summers (1991). It shows a strong negative relationship between machinery prices and quantities. It also shows that the high-quantity low-price economies are predominantly the fast-growing economies. This suggests that high machinery investment comes about through a move down and to the right along a machinery supply curve, as is shown in

the second panel of figure 11.

Here we report additional evidence, using a number of instruments plausibly more closely related to machinery supply conditions than to economic growth impulses produced by outside factors. We use three sets of instruments. First, we use our measures of national relative price structures from De Long and Summers (1991); the structure of relative prices in an economy is largely a function of its level of development and of the economic policies pursued by the government. Second, we use openness to trade as measured by World Bank estimates of tariff and non-tariff barriers in the 1980's, and by the average share of imports in GDP over 1960–85; tariff and non-tariff barriers are the result of explicit policies; the import share is in large part a product of past policy decisions and how they have shaped an economy's openness to the world market. Third, we use Lee's (1991) estimates of real machinery imports from the industrial core of the OECD; this provides us with an estimate of the effort devoted to machinery investment independent of errors or biases in the U.N. ICP benchmarks.

We have substantial confidence in the value of these instruments. We do not find it credible that rapid growth generated by exogenous sources leads to a relative price structure that makes it easy and cheap to invest in machinery, and hence to a high machinery investment share. We do not find it credible to suppose that rapid growth generated by other sources leads economies to quickly dismantle their trade barriers and become more open to machinery imports, and thus to higher machinery investment. We are less confident in the exogeneity of machinery imports, but we do think this instrumental variable provides us with a valuable control for biases and errors in the ICP benchmark-year estimates of quantity structures, on which so much of our data ultimately rest.

**Table 9**
**Instrumental Variables Regressions of Growth on Machinery Investment**

| | All Instruments | D&S Equip. Price | Lee Mach. Imports | Barriers & Imports[22] |
|---|---|---|---|---|
| Equip. Share | 0.278 | 0.320 | 0.324 | 0.229 |
| | (0.215) | (0.115) | (0.117) | (0.126) |
| Non-mach Share | 0.019 | 0.039 | 0.048 | 0.056 |
| | (0.062) | (0.043) | (0.041) | (0.043) |
| L Gr 60–85 | -0.183 | 0.013 | -0.024 | -0.044 |
| | (0.315) | (0.240) | (0.199) | (0.220) |
| Y/YUS60 | 0.030 | 0.033 | 0.027 | 0.019 |
| | (0.022) | (0.012) | (0.013) | (0.014) |
| $R^2$ | 0.128 | 0.230 | 0.243 | 0.168 |
| SEE | 0.0146 | 0.0146 | 0.0145 | 0.0146 |
| n | 38 | 57 | 77 | 67 |

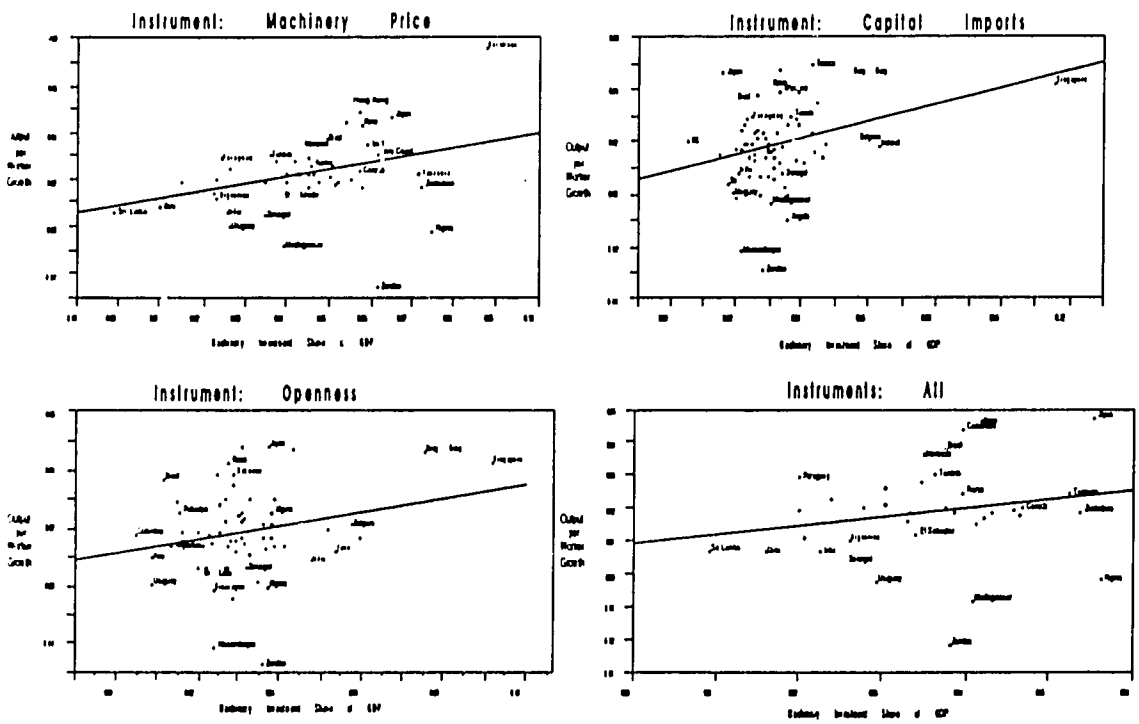
Table 9 reports our instrumental variable results using 1960–85 as our sample period, and using the machinery investment estimates constructed for the maximum cross-section sample. Figure 13 reports the partial scatter of growth and machinery investment in the different second-stage regressions.

The results using the relative price of machinery as an instrument for the machinery investment quantity are similar to results reported in De Long and Summers (1991). The estimated equation is shown in the second column of table 9, and the partial scatter in the first panel of figure 13. Results using the quantity of capital goods importedaccording to Lee (1991) as an instrument produce the equally strong results

[22]World Bank estimates of tariffs and non-tariff barriers on machinery imports in the 1980's, and the average share of imports in GDP over 1960–85.

shown in the third column of table 9, with the partial scatter shown in the second panel of figure 13. However, the quantity of capital goods imported may well not be exogenous—the relative price structure of an economy as measured by the relative price of machinery has a better claim to being independent of the residual in the growth rate equation.

**Figure 13**
**Partial Scatters of Growth and Machinery Investment from Second-Stage Instrumental Variables Regressions**




A better claim to exogeneity is possessed by variables that indirectly help determine the quantity of capital goods imported, but that are explicitly the result of economic policy choices. Tariffs and non-tariff barriers on machinery and equipment directly affect investors' and importers' willingness to purchase machinery from

abroad, and are clearly variables determined by economic policy. The average share of imports in GDP is also, largely, a variable determined by the sum total of policy stances that affect "openness": a larger share of trade in GDP has an immediate effect increasing machinery imports by increasing the potential pool of foreign exchange that could be used to buy foreign machinery.

Results using these "openness" determining variables as instruments are shown in the fourth column of table 9, and the partial scatter is shown in the third panel of figure 13. These results are somewhat weaker in support of machinery investment as a key to growth than those portrayed in the first two panels, but they still give a very prominent place to machinery investment as a determinant of growth. The final panel of figure 13 presents the partial scatter from the first regression in table 9, using all of the instruments. Unfortunately the sample size is relatively small, and the standard error of the machinery investment coefficient is relatively large. However, the point estimate is the same as in the other instrumental variables regressions.

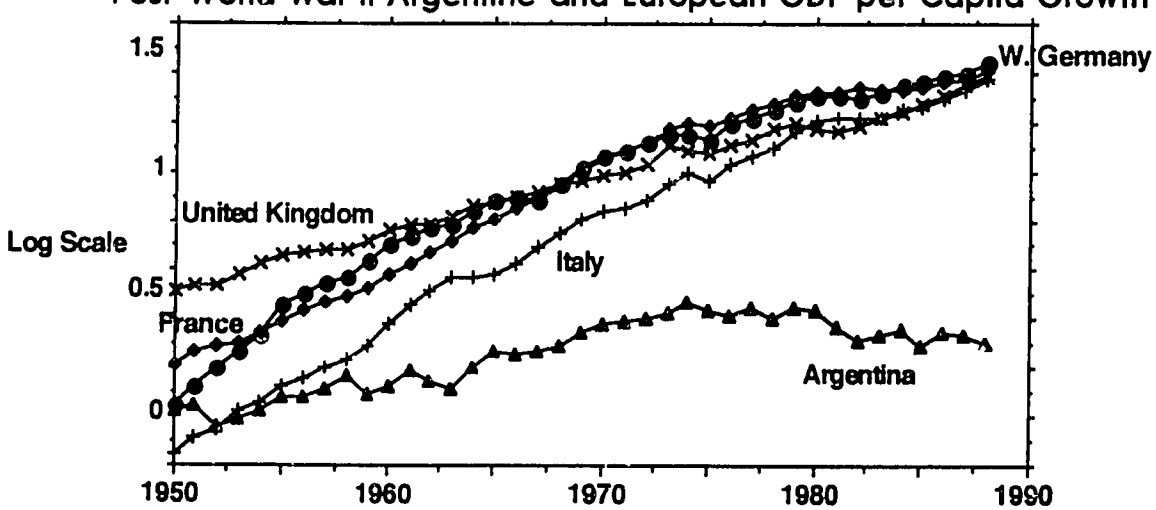
Different economies are the most influential observations in the different panels of figure 13, for each panel captures a somewhat different dimension of the machinery-growth scatter and uses a somewhat different sample. Nevertheless, they all generate qualitatively similar conclusions.

*Argentina's Stagnation*

Still another powerful line of evidence that the association between machinery investment and economic growth is a causal one, and that a high rate of machinery investment is more than a signal that fundamentals are attractive, comes from analyzing

exemplary case studies. Argentina's disappointing post-World War II growth history provides a particularly apposite example. According to Carlos Díaz-Alejandro, the rise of Perónism unintentionally crippled the Argentine economy's ability to invest in machinery. Díaz-Alejandro's tracing the sources of Argentinian post-World War II stagnation to the same factors that our cross-country regressions suggest are important determinants of growth lends very powerful support to our argument.

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




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 (Flick, 1982). In 1913 Buenos Aires had been perhaps thirteenth among cities of the world in telephones per capita (Hobsbawm, 1990). Yet by the late 1970's—even before the oil shock-induced borrowing sprees of the 1970's 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.

Like all countries outside of the inner industrial core, Argentina imported a large share of its machinery and equipment from abroad, primarily from Britain. This was efficient: first Britain and then the United States had enormous comparative advantages in producing producers' durable capital goods, and international transportation costs are a negligible fraction of the cost of such high value products. This pattern was destroyed by the Great Depression, which left Argentina justifiably suspicious of the free-trade order. America and Britain had, during the Depression, taken aggressive steps to shut Argentina out of their domestic markets and so preserve their own domestic employment at its expense.

In this environment an army officer, Juan Domingo 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.

All of 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. The resulting foreign exchange shortage provided Perón with only unattractive options, of which the best appeared to be the rationing of whole classes of imported goods. Perón and his advisors chose this 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.

Administrative controls were used to allocate newly-scarce foreign exchange. The consequences appeared minor in the short run: the raw materials and intermediate goods needed to maintain current operations had first priority. But machinery and equipment, last in the queue, could not be imported. 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. Thus the net effect of Perónist economic policies was an extraordinary rise in real capital goods relative prices in the 1940's, and a concommitant fall in investment in machinery and equipment. Each percentage point of national product saved produced less than half as much in terms of real investment after the war than would have been the case under other, liberal, outward-oriented economic policies. [23]

[23]The macroeconomic distortions that crippled Argentinian real investment were accompanied by microeconomic distortions as well. Díaz Alejandro laments that "the price mechanism became a tool to

Perón was overthrown and departed Argentina for Spain in 1953. But successor governments did not reverse his policies: the political forces he had mobilized still had to be appeased. Argentinian governments have remained committed to relative autarky, favoring urban over rural producers, terms of trade that disadvantaged rural producers, overvalued exchange rates, and unstable monetary policies throughout the post-World War II period. The government's hostility to foreign trade and foreign investment, and its desire to redistribute income towards the politically-powerful urban working classes 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. This, Díaz-Alejandro believed, was the principal source of slow Argentinian growth after World War II. Post-World War II Argentina has had a healthy national savings rate, but it has not been able to transform these savings into real investment in machinery and equipment.

It is difficult to interpret Argentina's low rate of machinery investment in the post-World War II world as a response to slow growth and low anticipated profits. Demand for that quantity of machinery that is imported and produced has in fact been relatively high: firms have been willing to purchase the quantities supplied at relative prices far exceeding world levels (Díaz-Alejandro, 1970). It is much more natural to see Argentina's low rate of machinery investment as a result of the economic policies it has adopted, in which case the relative stagnation that has in the post-World War II era reduced Argentinian relative living standards relative to those in Western Europe by two-thirds is powerful evidence of a causal link from machinery investment to growth.

redistribute income rather than to allocate resources....Severe bottlenecks had been allowed to develop in transportation, electricity, the supply of machinery and equipment, oil, and rural goods...the government neither allowed the price mechanism to reflect these imbalances in a steady fashion nor taken effective

*Caveat*

One *caveat* is necessary. 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. There is other evidence that boosts machinery investment that are not the results of market processes do not appear to produce large productivity gains. Machinery investment-boosting policies that are not market-conforming yield much lower benefits than our cross-section regressions suggest. 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?[24]

One interpretation is that we have given an incorrect interpretation to our data. In spite of our attempts to control for outside souces of growth, it may be that the growth-machinery nexus arises not because machinery investment causes rapid growth but because a high rate of machinery investment is a signal that other fundamental factors that make for rapid growth are favorable. In spite of our attempts to control for other factors, it may be that the growth-machinery association arises because a high rate of machinery investment and low relative prices for machinery are signals of general administrative and social competence.

A second interpretation is that the Soviet Union's high rate of investment in machinery and equipment did give it a much higher growth rate than it would

measures to remedy them by public investment."

[24]The USSR's gross investment share of GDP in peacetime years from 1929 to 1973 appears to have been between thirty and forty percent, of which approximately one-third was machinery. Yet output per worker growth over this period was probably no greater than the OECD average: less than two percent

otherwise have attained. Disappointing productivity growth in the Soviet Union would then be attributed not to the failure of investments in machinery to help workers learn skills and organizations learn procedures for efficiently handling modern technologies, but to the extraordinary costs of coordinating economic activity by the dead hand of the communist party. Under this interpretation we should dismiss the experience of the Soviet Union and the other centrally-planned economies—and perhaps of semi-socialized economies like those of Tanzania and Mozambique as well—as having been generated by a régime too different from that of mixed and market economies to yield any useful lessons.

We are attracted to yet a third interpretation: 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. However, growth is *not* likely to be much increased by investment-promotions that are market-replacing 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. Thus 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-substracting.

For an example closer to home, we should also not be surprised when the commands for more machinery investment issued by GM Chairman Roger Smith in the 1980's did not accelerate productivity growth in GM. General Motors invested more than 63 billion dollars in plant and equipment in the 1980's—more than four times current stockholders' equity, and enough to have purchased Toyota twice over (see Keller, 1989). But GM's massive 1980's investment program failed *ex ante* market tests. In the 1980's the stock market valued GM as worth only half as large a multiple of earnings or cash flows as its competitors like Honda or Volvo—only the extraordinary entrenchment of U.S. executives allowed Roger Smith to go through with his investment program given the stock market's extraordinary low valuation of its likely outcome.

By contrast, the American steel industry also invested heavily in the 1980's. But the firms that did the investing in the steel industry were small firms, with prospects that stock market saw as favorable *ex ante*, with few of the bureaucratic problems and inefficiencies of their larger competitors. And productivity in the American steel industry in the 1980's did grow rapidly (see Barnett and Crandall, 1986).

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.

## VI. Conclusion

We have documented here, as we argued before in De Long and Summers (1991), a very strong connection 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, and is as strong in the economies and subsections of the post-World War II era not analyzed in our previous work. 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.

We have also reported instrumental variables regressions that produce the same association between growth and machinery. Our instruments are in large part variables determined by economic policy that have direct effects on machinery investment rates, and only indirect effects on output per worker growth. Thus we conclude that the bulk of the growth-machinery investment relationship arises from a causal nexus between machinery and growth. The most plausible mechanism is that workers' skills and organizations' capacities to handle technologies are largely learned-by-doing. We believe that policies undertaken to generate more or less machinery investment by

altering the incentives of investors and firms in market economies have large effects on economic growth rates.

However, we suspect that even though machinery investment is a key to growth, market tests of the value of investment projects are essential to making machinery investment realize its productive promise. We suspect that the kinds of machinery investment promoted by market-conforming policies are the right kinds of machinery investment, and that the kinds of machinery investment produced by command mechanisms are relatively unproductive. Thus we believe that policies to shift incentives toward making machinery investment cheaper and easier are likely to yield enormous benefits. But we also believe in the essential role of market mechanisms: any governments that took the correlations we have documented here as evidence that they should embark on large-scale programs to control and direct machinery investment through command mechanisms would, we believe, be making a very large mistake.

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