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Human capital, equipment investment, and industrialization

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Abstract

This paper constructs simple models in which industrialization is driven by human capital accumulation. Industrialization can explain the robust correlation between equipment investment and growth in developing countries. We show that government intervention is justified within our stylized model, and indicate that a subsidy to equipment investment is likely to be dominated by other policies. In the final section of the paper, we examine the correlation between equipment investment and growth, and find that it is strongest in economies on the brink of industrialization. We also show that this result is not easily explained by diminishing returns. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

This paper examines the links between human capital, industrialization and equipment investment. The cross-section empirical growth literature has tended to neglect structural change, and we show how this may give misleading results in conventional studies of the relationship between equipment investment and economic growth.

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In a series of influential papers, De Long and Summers (1991, 1992, 1993, 1994) have suggested that there are strong externalities to equipment investment, perhaps taking the form of learning-by-doing on new machines. As they acknowledge, it may instead be evidence that equipment investment accompanies technology transfer. In this paper, we argue that equipment investment and growth are the joint outcome of industrialization, defined as a shift of employment from the traditional sector to the advanced one. As human capital rises, industrialization and productivity growth takes place, accompanied by equipment investment. Growth due to industrialization may be mistakenly attributed to relatively high equipment investment.

Clearly equipment investment will be a necessary part of industrialization. Our argument, though, is that industrialization is associated with productivity improvements that are not wholly dependent on equipment investment. Some productivity gains are independent of new machinery, and there may be additional benefits from the shift of labour out of agriculture, in which its marginal product is low due to various distortions. The productivity gains associated with structural change explain the high estimated returns to equipment investment. Hence, these high returns will be present only for developing countries in the early stages of industrialization.

To explore this, Sections 2 and 3 develop models based on the framework of Murphy et al. (1989a,b). We use the results to discuss the conditions under which a subsidy of equipment would be justified, and find that within our framework, it is likely to be dominated by alternative policies. By introducing a capital goods sector, we are also able to give some conditions for multiple equilibria that were not explored by Murphy et al. (1989a), thus extending their results.

We show that the incentives for equipment investment do matter for growth. However, they are a part of a wider process, industrialization, and analysis must take this into account. If the correlation between equipment investment and growth is primarily driven by industrialization, the coefficient on equipment investment in a cross-section regression will be misleading. It implies higher social returns to equipment investment than are actually present. This is because industrialization is likely to be accompanied by growth in total factor productivity, and regressions will mistakenly attribute faster growth to the accompanying equipment investment. If our argument is correct, we would expect to find little correlation between equipment investment and growth in relatively advanced economies, in which industrialization is largely complete. This idea is empirically tested in Section 4 of the paper.

2. Human capital and industrialization

In their study of industrialization, Chenery et al. (1986, p. 39) divide explanations of structural change into three categories. *Demand explanations* are based on the composition of demand, and particularly Engel's law that the share of food spending in consumption declines as consumption rises. *Trade explanations* emphasise shifts in comparative advantage as capital and skills accumulate. Finally, *technological explanations* rest on differential rates of productivity growth, reflected in relative prices. All the explanations rely on some exogenous motivation for structural change. For instance, that based on Engel's law obviously requires an increase in income from some unspecified source.

This section presents a model in which industrialization is driven by the accumulation of human capital. This is clearly compatible with any of the three explanations discussed above. In our model, though, no assumptions about Engel's law, trade patterns or exogenously given differential growth rates are required for industrialization to take place, at least if one interprets industrialization as the adoption of advanced, factory-based techniques.

We present a simple formal model of industrialization with a role for human capital. Imagine that manufactured goods can be produced in a simple cottage production sector, by traditional methods, or using more advanced techniques that are intensive in the use of human capital. When human capital is relatively scarce, the advanced techniques are too expensive to implement. With the accumulation of human capital, this changes, and the economy industrializes.

The underlying framework is due to Murphy et al. (1989a,b) and its extension by Matsuyama (1992). In each manufacturing sector, a potential monopolist decides whether or not to implement an increasing returns technique. For adoption, the market size must be large in relation to the fixed cost. As Murphy et al. (1989a,b) point out, this can explain several stylized facts of development, including the tendency for countries with large populations to industrialize relatively early (Chenery et al., 1986, p. 103).

For our purposes such models have two advantages. First, they will already be familiar to many readers as a simple model of industrialization. Secondly, the possibility of multiple equilibria discussed by Murphy et al. (1989b) reinforces our general argument. When underdevelopment traps are possible, the transition of some countries to an industrialized equilibrium will be associated with high equipment investment. However, this does not imply that subsidising equipment investment, the suggestion of De Long and Summers, is the best way out of an initial low-income equilibrium. Section 3 discusses this point in more detail, and draws out some conditions for multiple equilibria which are interesting alternatives to those suggested by Murphy et al. (1989b).

Models of development which emphasise market size are sometimes criticised on the grounds that domestic market size is irrelevant when goods can be exported. Murphy et al. (1989b) discuss this criticism and cite evidence that, in practice, trade is not costless and the domestic market plays an important role. In particular, the intensive export of manufactures tends to begin only once an industry has become established in the domestic market (Chenery and Syrquin, 1975). After discussing the evidence, Murphy et al. conclude that "whether the causes of limited trade are natural, such as transport costs or taste differences among countries, or man-made, such as tariffs, the bottom line is the overwhelming importance of domestic demand for most of domestic industry" (1989b, p. 1007).[1]

Our emphasis on market size and human capital in determining industrialization is also present in the model of Goodfriend and McDermott (1995). The feeling that market size is important to industrialization is a common one, and the introduction of human capital qualifies the scale effect of population, rendering market size models more plausible. Their paper differs from ours in its emphasis on early development, and particularly the onset of the Industrial Revolution. Our work is intended to have greatest relevance to present-day developing countries. Here the interesting questions surround not the development of new techniques, but the conditions determining the adoption of existing ones from abroad. The model presented here can thus be seen as an investigation of the determinants of technology transfer and equipment investment.

We now describe our model, drawing on Murphy et al. (1989b) and Matsuyama (1992). There is a representative consumer who derives utility from consuming food, and a variety of manufactured goods distributed over the unit interval. Utility is given by

$$(1-\beta)\int_0^1 \ln(c(z))\,\mathrm{d}z + \beta\ln(n-n_0) \tag{1}$$

where n is food consumption and $\beta \in (0,1)$ is the marginal budget share of food. These preferences mean that Engel's law is satisfied. As income rises, the share of food in consumption falls. Together, the budget constraint and preferences imply that spending on manufactures is given by

$$d = (1-\beta)\left(y - \frac{n_0}{A}\right). \tag{2}$$

The consumer is endowed with L units of labour, supplied inelastically, which are of quality h. This can be thought of as an index of human capital, but we rule out investments in education and training. Hence there is no role for saving and the consumer seeks to maximise current utility in each period.

We take the numeraire to be the consumer's wage. Income is given by aggregate profits plus the return to labour:

$$y = \Pi + L. \tag{3}$$

[1] One reason market size may be important is that firms require domestic supplies of producer services and other non-tradeables. See Rodríguez-Clare (1996).

The specification of the agricultural and equipment sectors is very simple. In the agricultural sector, one unit of labour input produces A units of output, so if agriculture is competitive the price of food will be given by $1/A$. Similarly, one unit of labour produces λ units of equipment. This is sold in a competitive market at price e, using the same numeraire as before, so a zero-profits condition again implies that $e = 1/\lambda$. Alternatively, in much of what follows, one could take the prices of food and equipment as exogenously given by world markets.

There is a continuum of manufacturing sectors, indexed by $q \in [0, 1]$ and each producing one of the goods $x(q)$. In each sector, there are two types of firms. A competitive fringe converts one unit of labour input into one unit of output. This is the cottage production element of the economy. Free entry into cottage production implies zero profits, and hence the price of each good is one.

Second, there is a single firm in each sector with access to a modern increasing returns technology. Use of this advanced technique requires a fixed cost of $F(q)/h$ units of labour. This is perhaps the simplest way to make the cost of adopting the advanced technique depend on the level of human capital. In this paper, the fixed cost $F(q)/h$ is increasing in q, so that goods towards the right-hand end of the continuum are relatively sophisticated and require the payment of a higher fixed cost to produce. As we will see, these goods are produced at a relatively late stage of industrialization.

As well as paying the fixed cost, firms adopting the advanced technique must use equipment. This corresponds to the stylized fact that production becomes more intensive in the use of intermediate inputs as industrialization takes place. For simplicity, equipment is not durable and the technology is fixed coefficients, each unit of output requiring one unit of equipment and $1/\alpha$ units of labour, where $\alpha > 1$.

The advanced firm in each sector decides whether to industrialize or abstain from production. If it produces, then it charges a price of one. Anything higher would mean losing all its customers to the competitive fringe, whilst a lower price is ruled out by the presence of a unit elastic demand curve. Selling goods at a price of one, the profit of the advanced firm in sector q is given by

$$\pi(q) = d - l - ed = d - \frac{d}{\alpha} - ed - \frac{F(q)}{h} = ad - \frac{F(q)}{h} \tag{4}$$

where

$$a = 1 - \frac{1}{\alpha} - e \tag{5}$$

and a is the advanced firm's mark-up. We assume $a > 0$ to ensure that positive profits are possible. When a fraction x of the firms industrialize, aggregate profits are given by

$$\Pi(x) = xad - \frac{1}{h}\int_0^x F(i)\,\mathrm{d}i. \tag{6}$$

Substituting Eq. (6) in $y = \Pi + L$ we have

$$y = xad - \frac{1}{h}\int_0^x F(i)\,\mathrm{d}i + L\,.$$

Using Eq. (2) we can solve for d and y to get

$$d(x) = \frac{(1-\beta)[L - (n_0/A) - (1/h)\int_0^x F(i)\,\mathrm{d}i\,]}{1 - a\,(1-\beta)x}\,, \tag{7}$$

$$y(x) = \frac{L - a(1-\beta)x(n_0/A) - (1/h)\int_0^x F(i)\,\mathrm{d}i}{1 - a(1-\beta)x}\,. \tag{8}$$

Sector q will industrialize if $ad(q) \geq F(q)/h$, and from this we can derive the condition for sectors indexed by $[0, q]$ to industrialize, which is

$$h \geq \left[\frac{1}{L - (n_0/A)}\right]\left[\frac{F(q)[1 - a(1-\beta)q]}{a(1-\beta)}\right] + \left[\frac{1}{L - (n_0/A)}\right]\int_0^q F(i)\,\mathrm{d}i\,. \tag{9}$$

Given that $F(q)$ is increasing in q, differentiating Eq. (9) makes clear that the required threshold is also increasing in q. If the level of human capital is rising, perhaps as a result of increased schooling, then so will the extent of industrialization as measured by q, until $q = 1$ is reached. The level of development is determined by the level of human capital.[2]

Since any firm that industrializes must cover the fixed cost, output is clearly increasing in x. Since labour input is constant at L, this means that labour productivity increases as industrialization takes place. Also note that our extension qualifies the standard prediction of market size models. In a simple model, it can be difficult to explain why countries with large populations have not always become industrialized; China is an obvious example. With the addition of human capital, it becomes clear that a large population may not be

[2] This is consistent with case studies. De Long (1992) argues that slow growth in Argentina was largely the outcome of import tariffs on capital goods. However, another feature of post-war Argentina is its relatively low investment in human capital.

enough. Human capital may be so low that it remains prohibitively expensive to adopt the advanced technique.[3]

In all of the above, and what follows, we have taken human capital as exogenous. For the present model of developing country growth, we feel that this is probably a satisfactory approach. Cross-country differences in schooling and training institutions are perhaps likely to account for much of the international variation in human capital. Perhaps more importantly, although it would be possible to endogenize human capital by setting up a simple learning-by-doing mechanism, or school enrollments related to income, we feel that this would add little insight.

A model like ours, in which market size and human capital are important, points to the need to sequence development rather than embark on a Big Push. This has sometimes been emphasised in connection with the experience of East Asia (for instance, Ito, 1994). A country with relatively low human capital should seek to first master relatively basic industries. In doing this, it is likely to encourage the development of a human capital base (including, for instance, management skills) and a larger market size, both of which will make it easier to develop more advanced industries, perhaps the ones that have higher fixed costs.

Note that Eq. (9) is decreasing in a, the mark-up in the advanced sector. Anything which acts to raise the mark-up will mean that the fixed costs can be covered at a smaller market size, and the spread of the advanced technique will be wider. From Eq. (5), the mark-up is decreasing in equipment prices. For a given level of human capital, anything which lowers the price of equipment, like improved productivity or lower tariffs on equipment imports, will raise the mark-up and lead to the modern technique being adopted by more sectors.[4]

Since $d(x)$ is increasing in x, and $xd(x)$ units of equipment are used in production, low equipment prices (and hence a high mark-up) will often be associated with rapid growth and high equipment investment, which is the empirical finding of De Long and Summers (1991). They suggest a tax credit for equipment investment to raise growth, but other policies may be at least as effective.

Within this model, government intervention is clearly justified, because pecuniary externalities are present. A firm that adopts the advanced technique creates profits that raise the demand for other manufactures, allowing adoption of the advanced technique elsewhere. The government could encourage this by

[3] In a more complete model, there could also be a role for transport costs, so that countries with large populations might also have poorly integrated regional markets. See Romer (1996) for a discussion of the USA as a well integrated market.

[4] Given this effect of the mark-up, one simple modification which reinforces our results is to make labour productivity in the equipment sector increasing in human capital. For instance, if each worker in the equipment sector produces λh units of equipment, the price of equipment will be $1/\lambda h$ and so will fall as human capital rises, raising the mark-up in the advanced sector.

raising the mark-up, using a lump sum tax to subsidise output in the modern sector. Increased adoption of the modern technique must raise welfare, since income rises while prices are unchanged. In practice, a useful policy could take the form of subsidising the output of companies that have been granted licences to use foreign technology. Obviously, one should be wary about drawing policy conclusions from a model as stylized as this one. However, this policy recommendation is potentially a robust one. The adoption of technology from abroad is likely to have other spillovers, beyond those to demand.

Subsidising equipment investment is an obvious alternative, and this is advocated by De Long and Summers: "policies to shift incentives toward making equipment investment cheaper and easier are likely to yield enormous benefits" (1994, p. 51). Although such a policy could be justified in our model as it stands, this result may not be robust to minor changes in assumptions. It is likely that equipment is used in sectors other than the modern one, for instance in the less dynamic parts of the industrial sector, like mining, construction, and electricity generation. This will reduce the effect of a given subsidy expenditure on the mark-up of manufacturing firms contemplating the advanced technique. Broadly speaking, it seems likely that equipment subsidies will be less effective than measures aimed directly at the emerging advanced sector.

As a general point, it is interesting to note how minimal the departures from orthodox assumptions need to be for intervention to be justified. There is a continuing debate about the importance of policy interventions in the East Asian economies (Page, 1994). Industrial policies have often been designed to shift industrial structure towards newer and more modern sectors. Measures like credit subsidies to advanced firms can be seen as ways of raising their mark-ups, or more broadly the incentives to adopt modern techniques. Although some writers have concluded that the overall effect of these measures has been small, it is clear that one can justify intervention without making complicated or counter-intuitive assumptions.

In this stylized model, there will be a definite tendency for industrialization to spread across the world, even in the absence of rising human capital in particular countries. Any improvement in agricultural productivity, reflected in a rise in A, increases the spread of modern techniques. So will any improvement in the productivity of the modern technology (which raises α) or the manufacture of equipment. Any of these changes could come about as a result of world technical progress. Thus, as time and technology march on, countries will tend to industrialize at lower and lower levels of human capital and income.

3. Multiple equilibria

Work of Murphy et al. on industrialization is best known for some simple but ingenious models of the Big Push. The central idea is that the simultaneous modernization of many sectors, or a Big Push, can be profitable for them all at times when no single sector can make a profit by industrializing on its own. This contrasts with our own emphasis on the possible need to sequence the development of advanced sectors.

The formal model Murphy et al. (1989a) present demonstrates the possibility of two equilibria for given parameter values, so that a Big Push corresponds to a move from a bad (undeveloped) to a good (industrialized) equilibrium. In their models, multiple equilibria arise when firms that use the advanced technique contribute to the market for other manufactures, even when their investment on its own would lose money. They suggest several mechanisms by which this can occur, including a factory wage premium and investments with delayed pay-offs. Our introduction of intermediate inputs suggests that the conditions for multiple equilibria are more general.

In particular, a simple way to obtain multiple equilibria is to posit imperfect competition in the manufacture of equipment. Firms that use the advanced technique and purchase equipment inputs will contribute to the profits of the equipment manufacturer and, in turn, to the demand for manufactures. This effect can be reinforced if there are scale economies in the equipment sector. Then, an expansion by one advanced firm can potentially lower the price of equipment, raising the mark-ups of other advanced firms.

We use a simple model to demonstrate the first of these possibilities, with fixed costs the same across sectors, and no role for agriculture. Equipment can be manufactured by a competitive fringe at a price e. A monopolist can also produce equipment, using a more sophisticated technology, which converts a unit of labour into ϕ units of equipment. To separate out the profits effect from that of reduced equipment prices, we simply assume that demand is sufficiently inelastic that the advanced firm will not want to charge a price less than e.[5] With this specification, profits in the equipment sector are given by $(e - 1/\phi)xy$. Here and later on, we assume by choice of parameters that positive profits are possible.

In the consumer manufactures sector, the advanced firm can combine one unit of labour with α units of equipment to produce α units of output, but must pay a fixed cost F/h to produce. Manufacturing profits are then given by

$$\pi = \left(1 - \frac{1}{\alpha} - e\right)y - \frac{F}{h}.$$

[5] This also allows us to avoid deriving the demand curve for equipment, which is complex, depending as it does on the number of sectors industrializing.

Aggregate profits are given by summing profits in consumer manufacturing and those in equipment:

$$\Pi(x) = \left(1 - \frac{1}{\alpha} - e\right)xy - x\frac{F}{h} + \left(e - \frac{1}{\phi}\right)xy .$$

Substituting this in the equation for aggregate income, $y(x) = \Pi(x) + L$, gives

$$y(x) = \frac{L - x(F/h)}{1 - (1 - (1/\alpha) - (1/\phi))x} .$$

If firms indexed by $(0, q)$ industrialize, the profits of firm q will be given by

$$\pi(q) = \left(1 - \frac{1}{\alpha} - e\right)\left[\frac{L - q(F/h)}{1 - (1 - (1/\alpha) - (1/\phi))q}\right] - \frac{F}{h} .$$

If $\pi(0) \geq 0$, then $\pi(q)$ is definitely increasing in q. This means that, if $\pi(0) \geq 0$, then the unique equilibrium has all advanced firms industrializing. It is also possible for industrialized and non-industrialized equilibria to co-exist, the case when $\pi(0) < 0$ but $\pi(1) > 0$. When $\pi(1) > 0$, it definitely pays all sectors to industrialize, even in cases where any industrializing alone would make a loss.

For industrialization to be the unique outcome, $\pi(0) \geq 0$, so

$$h \geq \frac{F}{L(1 - (1/\alpha) - e)} . \tag{10}$$

Note that increased productivity using the modern technique (a rise in α) means that a lower level of human capital is required to give a unique equilibrium. As worldwide technical knowledge improves, and human capital accumulates, the relevance of the Big Push will diminish.

For full industrialization to be a possible outcome, $\pi\,(1) \geq 0$, so

$$h \geq \frac{(1 - e + (1/\phi))F}{L(1 - (1/\alpha) - e)} . \tag{11}$$

For multiple equilibria, we need the inequality in Eq. (10) to be reversed, and this equation to hold simultaneously with Eq. (11). Multiple equilibria exist for an intermediate range of human capital:

$$\frac{F}{L(1 - (1/\alpha) - e)} > h \geq \frac{(1 - e + (1/\phi))F}{L(1 - (1/\alpha) - e)} \tag{12}$$

and can occur only if the mark-up in the equipment sector, $e - (1/\phi)$, is positive. The intuition for multiple equilibria is simple. Any advanced firm adopting the modern technique contributes to profits in the sector producing intermediate inputs, and so contributes to the demand for manufactures. Thus even if a firm would make a loss by industrializing on its own, it may make a profit if all firms industrialize, because higher profits in the intermediate sector will raise demand for manufactures.

Multiple equilibria will also be present if there are economies of scale in the manufacture of intermediate inputs like equipment. With an imperfectly competitive equipment sector, this seems to follow immediately from our previous result, because profits in the equipment sector will be non-zero. However, it is easy to see that there will be an effect of scale economies even in the absence of a profits effect. One firm, by raising output, can lower the price of equipment if there are scale economies in equipment manufacture. In turn, this fall in the price of equipment will increase the incentive to adopt the advanced technique. It can therefore be profitable for all firms to adopt simultaneously, even when a firm adopting alone would make a loss.

In principle, a model in which transitions between multiple equilibria are possible reinforces our core argument that cross-country regressions may overstate the social returns to equipment investment. For countries in an underdevelopment trap, the returns to investment may be low, as in the work of Rodríguez-Clare (1996). If something happens to shift the economy towards a 'good' equilibrium, such as a rise in human capital, then growth will take place accompanied by equipment investment.[6] In retrospect, it will seem as if equipment investment has played a strong initiating role, and that subsidies to equipment would be a useful policy measure. In fact, depending on the nature of the underdevelopment trap, equipment subsidies may be dominated by other interventions, for the reasons discussed earlier.

4. Empirical testing

We now turn to an empirical test of our central idea. If our emphasis on structural change is correct, one would expect the correlation between growth and equipment investment to be strongest in those developing countries with a lot of potential for industrialization, and hardly present at all in countries where structural transformation is almost complete. Thus, our framework can be seen as a resolution of the puzzle implicitly posed by Auerbach et al. (1994): why is the investment–growth relationship strong in developing countries, but not in Western Europe, or within the OECD? The likely answer is that the relationship is driven by the presence of structural change, and the empirical work described below supports this idea.

There are several natural variables we can use to capture an initially underdeveloped state. Using data for 1960, then low energy consumption per capita,

[6] Azariadis and Drazen (1990) make the point that multiple equilibria could be driving the much-studied correlation between initial schooling and growth.

a low degree of urbanization, a low value for the share of manufacturing in employment or GDP, or a high share of agriculture in employment, are all likely to indicate that industrialization had a long way to go over subsequent years. Which of these variables should we choose? In practice, the choice is unlikely to matter a great deal, since the rank correlations between these variables are all high.

Our method is to follow Abizadeh and Basilevsky (1986) and combine the variables into a single measure, using factor analysis. Although factor analysis is sometimes controversial, in this case it can be thought of as a relatively elegant way of averaging across the variables to find an index corresponding to 1960 industrialization.[7] The factor loadings for our five variables, estimated by maximum likelihood, are shown in Table 1, while Table 2 ranks the countries by the derived index of industrialization (the factor scores, calculated by regression). All five correlations in Table 1 have the expected signs. There are one or two possible anomalies in Table 2 – for instance, the USA is only in fifth place – perhaps generated by the tendency for manufacturing shares of employment to fall at high levels of development. The city states, Hong Kong and Singapore, are placed highly because of their high urbanization and low specialization in agriculture. The low position of Japan is explained by its large agricultural sector in 1960: around a third of the labour force worked in agriculture, compared to just 4% in the UK. It is also worth noting that Japan's GDP per worker in 1960 was only 20% of the USA's, according to version 5.6 of the Penn World Table. Overall, the ordering of countries by our index of 1960 industrialization seems reasonable.

To test whether the importance of equipment investment depends on industrialization, we stratify the sample into the three groups shown in Table 2. Then we estimate the central regression from De Long and Summers (1993) for each group. Cross-country growth regressions of this type are highly sensitive to outliers, and Auerbach et al. (1994) argue that the De Long and Summers (1993) results are driven by the presence of Botswana in the sample. In this paper, we take great care to ensure that our results do not depend on one or two influential observations. We first estimate our regressions using a robust estimator, least trimmed squares, and then use the residuals to identify outliers. Countries with large residuals in the robust regression are excluded from an OLS regression. For each table below, we provide details of which countries have been excluded. Among the poorest economies in 1960, Botswana and Zambia are frequently excluded by our technique. Both these countries were identified as problematic by De Long and Summers (1991), which suggests that our method is a useful one.

[7] For more on factor analysis, see any standard text on multivariate analysis, for instance Chatfield and Collins (1980) or Mardia et al. (1979).

Table 1
Factor loadings for the five industrialization variables

	F_1
Ag. share of employment	– 0.99
Energy consumption	0.73
Manuf. share of employment	0.96
Manuf. share of GDP	0.85
Urbanisation	0.89

Note: All data for 1960. There are 67 countries in the analysis. Data on agriculture and manufacturing employment shares are from World Bank (1979); remaining series are from World Bank (1980).

Table 2
Ranking of countries by 1960 industrialization index

Group 1	Index	Group 2	Index	Group 3	Index
United Kingdom	1.83	Spain	0.47	Ghana	– 0.53
Hong Kong	1.70	Jamaica	0.30	Malaysia	– 0.55
Belgium	1.65	Portugal	0.29	Dominican Rep.	– 0.56
(West) Germany	1.59	Colombia	– 0.03	Algeria	– 0.61
USA	1.58	Peru	– 0.06	South Korea	– 0.64
Netherlands	1.54	Mexico	– 0.06	Honduras	– 0.72
Australia	1.47	Brazil	– 0.07	Angola	– 0.78
Sweden	1.46	Costa Rica	– 0.09	India	– 0.79
Canada	1.31	Greece	– 0.15	Nigeria	– 0.82
Israel	1.24	Panama	– 0.15	Turkey	– 0.90
Denmark	1.21	The Congo	– 0.17	Zaire	– 1.09
Austria	1.21	Paraguay	– 0.19	Mozambique	– 1.12
Singapore	1.21	Taiwan	– 0.21	Senegal	– 1.13
Argentina	1.16	Ecuador	– 0.24	Benin	– 1.19
France	1.12	Tunisia	– 0.28	Kenya	– 1.25
Norway	1.01	Sri Lanka	– 0.34	Ethiopia	– 1.30
Uruguay	0.99	Philippines	– 0.37	Somalia	– 1.32
Italy	0.90	Bolivia	– 0.37	Ivory Coast	– 1.35
Trinidad	0.90	Nicaragua	– 0.37	Uganda	– 1.37
Chile	0.76	El Salvador	– 0.39	Tanzania	– 1.39
Japan	0.73	Pakistan	– 0.39	Papua New Guinea	– 1.39
Finland	0.55	Morocco	– 0.45	Madagascar	– 1.48
				Mali	– 1.50

The exclusion of a few outliers from each regression is sometimes important to our results, and requires more discussion. We would argue that exclusion is justified on two general grounds. Remember that an observation is excluded when it is some distance away from the regression surface estimated by least trimmed squares. One reason for this may be that the observation incorporates a substantial amount of measurement error, and therefore should not be allowed to overly influence the results. In this case, though, the countries excluded from the regressions should be common across different models. In practice, they are not.

We can justify this by our second motivation for excluding outliers, which is more subtle and has wider applicability. A common objection to cross-country growth regressions is that the countries are unlikely to lie on a common surface. Equivalently, parameter heterogeneity is thought likely. When we impose a simple constant-parameter model on the data, the fact that it is only a rough approximation is likely to mean that some observations emerge as outliers. Use of least trimmed squares acknowledges this problem, since it can be seen as an attempt to characterize the most coherent part of the data. Our subsequent step, excluding a few outliers from an otherwise straightforward OLS regression, is an example of 're-weighted least squares' or RWLS, as recommended by Rousseeuw and Leroy (1987). The technique should ensure that, unlike the results of De Long and Summers (1991) and Auerbach et al. (1994), our own findings cannot be explained by any small group of outlying observations.

Our adoption of the same empirical framework as De Long and Summers (1993) also requires further discussion. It has the advantage that it allows our findings to be directly comparable with those of De Long and Summers. The disadvantage is that our results are likely to share the same flaws: in particular, the investment variables are endogenous. Unfortunately, convincing instruments are difficult to find. Temple (1996) experiments with using the lagged level of investment as an instrument for first differences, and finds that controlling for simultaneity bias in this way does not wholly explain De Long and Summers' results, although the instruments may be weak. In any case, as we shall see, endogeneity bias cannot be used to explain our central finding.

The RWLS results from stratifying the sample are presented in Table 3. The central interest lies in the equipment coefficient, and how it is related to growth in the different subsamples. The correlation is strongest in the least developed economies, and hardly present at all in countries which had clearly industrialized by 1960. If equipment investment causes total factor productivity growth, as De Long and Summers argue it does, then one would expect a strong correlation regardless of the particular subsample. In practice, the correlation seems to be weak in countries which have already industrialized. Note that it would be hard to explain this finding in terms of the endogeneity of the equipment investment variable.

We also tried stratifying the sample using 1960 data for the agriculture and manufacturing shares of employment, and the secondary school enrollment ratio. These results are shown in Tables 4–6. The results are very similar: a high growth–equipment investment correlation in the least industrialized countries, falling with the extent of initial industrialization, to a negligible effect in the

Table 3
Regressions stratifed by industrialization index

Industrialization index	Equipment investment	Other investment	Log GDP per worker (1960)	Labour growth	R^2	n
< -0.50	**0.447**	0.373	− 0.022	0.353	0.95	19
	(0.068)	(0.044)	(0.003)	(0.226)		
$\geq -0.50, < 0.50$	**0.360**	0.075	− 0.007	− 0.272	0.79	19
	(0.085)	(0.032)	(0.005)	(0.251)		
≥ 0.50	**0.066**	0.000	− 0.026	− 0.010	0.91	19
	(0.061)	(0.036)	(0.004)	(0.119)		

Regression	Countries excluded
1	India, Kenya, Somalia, Tanzania
2	Jamaica, Morocco, Taiwan
3	Argentina, Chile, Uruguay

Note: Figures in parentheses are MacKinnon and White (1985) jackknife heteroscedasticity consistent standard errors. When all observations are included, the equipment investment coefficients for the three groups are 0.58, 0.43, and 0.23, respectively.

Table 4
Regressions stratifed by agriculture share of employment

Agriculture employment share	Equipment investment	Other investment	Log GDP per worker (1960)	Labour growth	R^2	n
$\geq 80\%$	**0.518**	0.089	− 0.011	− 0.290	0.87	20
	(0.353)	(0.048)	(0.003)	(0.306)		
$\geq 60\%, < 80\%$	**0.157**	0.415	− 0.031	0.505	0.85	16
	(0.154)	(0.095)	(0.010)	(0.424)		
$\geq 40\%, < 60\%$	**0.371**	0.129	− 0.003	− 0.056	0.99	12
	(0.048)	(0.014)	(0.002)	(0.080)		
$< 40\%$	**0.191**	0.005	− 0.010	− 0.248	0.71	22
	(0.042)	(0.026)	(0.003)	(0.149)		

Regression	Countries excluded
1	Mali, Thailand
2	Guatemala, India, Morocco, Zambia, Zimbabwe
3	Jordan, Paraguay, Spain, Taiwan, Tunisia
4	Chile, Hong Kong, Jamaica, Japan
	Singapore, Uruguay

Note: Overall sample is based on De Long and Summers (1993). Figures in parentheses are MacKinnon and White (1985) jackknife heteroscedasticity consistent standard errors. When all observations are included, the equipment investment coefficients in the four samples are 0.44, 0.54, 0.45 and 0.27, respectively.

industrial economies. This similarity of the results is not surprising, since the various indicators of potential for industrialization are highly correlated, with Spearman's rank correlations between 0.8 and 0.9. Clearly, our results are robust to the precise way the sample is stratified by the extent of prior

Table 5
Regressions stratifed by manufacturing share of employment

Manufacturing employment share	Equipment investment	Other investment	Log GDP per worker (1960)	Labour growth	R^2	n
< 10%	**0.809**	0.027	− 0.007	− 0.214	0.85	18
	(0.128)	(0.054)	(0.004)	(0.262)		
≥ 10%, < 20%	**0.417**	0.103	− 0.001	− 0.178	0.80	26
	(0.085)	(0.027)	(0.004)	(0.196)		
≥ 20%, < 35%	**0.145**	0.124	− 0.020	0.420	0.94	13
	(0.073)	(0.044)	(0.004)	(0.186)		
≥ 35%	**0.030**	− 0.036	− 0.023	0.055	0.96	13
	(0.061)	(0.032)	(0.005)	(0.120)		

Regression	Countries excluded
1	Botswana, Cameroon, Madagascar, Mali Mozambique, Thailand, Zambia
2	Angola, Morocco, Nigeria, Paraguay, Taiwan
3	Jamaica, Mauritius, Spain
4	Argentina, Italy, United Kingdom

Note: Overall sample is based on De Long and Summers (1993). Figures in parentheses are MacKinnon and White (1985) jackknife heteroscedasticity consistent standard errors. When all observations are included, the equipment investment coefficients in the four samples are 0.49, 0.49, 0.23, and 0.18, respectively.

industrialization. Note that the results are particularly clear cut when the human capital variable, secondary school enrollment, is used to stratify the sample (Table 6).

Stratification by initial income gives similar results, and so one interpretation of our regressions is that they simply demonstrate diminishing returns to equipment investment. The problem with this argument is that it implies enormously high returns to equipment investment in the early stages of development. De Long and Summers (De Long and Summers, 1992, p. 186) present calculations that a net rate of return as high as 45% implies a coefficient of just 0.16 in a regression over 25 years. Yet we find a coefficient of 0.45 in the poorest economies (see Table 3). Making the same calculations as De Long and Summers (1992), this coefficient implies a rate of return to equipment investment greater than 150%.[8] It is hard to believe, to say the least, that returns of this magnitude could have persisted over any length of time across the majority of developing countries.

[8] This figure is based on the same depreciation rate used by De Long and Summers, 15%. Assuming a depreciation rate for equipment as low as 5% results in an estimated rate of return over 50%.

Table 6
Regressions stratifed by 1960 secondary school enrollment

Secondary school enrollment ratio	Equipment investment	Other investment	Log GDP per worker (1960)	Labour growth	R^2	n
< 5%	**0.477**	0.132	− 0.012	− 0.597	0.98	17
	(0.022)	(0.028)	(0.002)	(0.212)		
≥ 5%, < 20%	**0.320**	0.111	− 0.002	− 0.481	0.91	16
	(0.089)	(0.023)	(0.003)	(0.250)		
≥ 20%, < 40%	**0.208**	0.091	− 0.007	0.220	0.94	14
	(0.045)	(0.047)	(0.003)	(0.127)		
≥ 40%	**0.061**	− 0.034	− 0.023	− 0.020	0.97	15
	(0.029)	(0.026)	(0.002)	(0.084)		

Regression	Countries excluded
1	Angola, Cameroon, Ivory Coast, Madagascar Mali, Mozambique, Rwanda, Zambia
2	Morocco, Nicaragua, Pakistan, Paraguay, Thailand, Tunisia
3	Hong Kong, India, Italy, Jordan, Korea Portugal, Spain, Taiwan
4	Jamaica, Japan, United Kingdom

Note: Overall sample based on De Long and Summers (1993). Figures in parentheses are MacKinnon and White (1985) jackknife heteroscedasticity consistent standard errors. Omission of Botswana from the first regression gives a point estimate for the equipment coefficient of 0.46, and raises the HCSE to 0.12. When all observations are included, the equipment investment coefficients in the four samples are 0.43, 0.32, 0.33, and 0.25, respectively.

Our own answer to this puzzle is that attempting to impose the framework of an aggregate production function is almost certainly the wrong approach for many developing countries, at least for those on the verge of industrialization. Models which emphasize the role of structural change are likely to have greater relevance. In our own framework, there is little or no equipment investment at the pre-industrial stage. The small size of the market means that the returns to equipment investment are low.[9] As human capital and world knowledge rise, this starts to change, and it becomes profitable to invest in equipment while adopting more advanced techniques. TFP growth will be relatively strong in the countries that are industrializing, explaining the pattern of coefficients in the above regressions.

De Long and Summers claim that coefficients like those in the above tables can only be explained if there is a divergence of private and social returns, perhaps because of learning-by-doing on new machines. They are able to show

[9] See Rodríguez-Clare (1996) for a formalization of this idea.

that their measures of total factor productivity growth are correlated with investment in equipment, and possibly with that in structures as well (1992, pp. 191–192). However, if it is the case that equipment investment raises TFP growth, it is hard to understand why the coefficient on equipment investment varies so greatly across subsamples, and why there is little correlation in the most developed countries.

It is possible to argue that equipment investment only causes TFP growth at low levels of productivity, but it is hard to see why the commonly suggested mechanisms, like learning-by-doing on new machines, are not at least as strong in richer economies. It is also difficult to see how TFP growth could be brought about by investment in structures. In our view, a more plausible explanation of the correlation between TFP growth and investment is that both are the outcome of industrialization. As human capital rises, modern techniques are adopted, leading to rapid TFP growth accompanied by high investment in equipment and structures.

One argument made by De Long and Summers (1991) is that if other factors draw investment in their wake, one would expect the link between investment and growth to be as strong for structures as for equipment. In our view, industrialization provides a counter argument. It seems likely that in the course of structural transformation, investment in advanced capital goods is likely to assume particular importance.

As industrialization takes place, any variation in other determinants of equipment investment may have only a minor independent role. In our model, exogenous falls in equipment prices do make industrialization more likely, and raise equipment investment. De Long and Summers (1991) use the negative relationship they find between equipment prices and investment to argue that causality runs from exogenous determinants of investment to growth. Our own argument is that causality runs from determinants of industrialization (including equipment prices) to both investment and TFP growth. The coefficient on equipment investment in a growth regression is likely to be misleading, because it will tend to imply higher social returns to exogenous variation in equipment investment than those actually present.

5. Conclusions

We have presented a simple model in which the pace of industrialization is determined by the accumulation of human capital. Higher levels of human capital lower the cost of adopting advanced techniques, increase their diffusion, and so the growth of the manufacturing sector is naturally accompanied by equipment investment. This association can help explain the positive cross-country relationships between equipment investment and growth in per capita income or total factor productivity.

The empirical evidence is compatible with our general argument. The relationship between equipment investment and growth is strongest in countries that are initially poor, indicating that the correlation may be driven by industrialization. The standard explanation in terms of an aggregate production function – with diminishing returns to equipment investment – implies massive rates of return to investment in the developing countries, far higher than those usually observed or thought reasonable. Since structural change can be used to explain the relationship, there is no need to resort to claims of high social returns driven by learning-by-doing externalities, for which the direct evidence is weak. The finding that there is a low correlation in those countries already industrialized in 1960 suggests that our interpretation is likely to be the correct one.

An important underlying claim in De Long and Summers' work is that equipment investment is exogenously determined by, for instance, trade policies. Interventions that encourage equipment investment will raise growth, at least over the medium term. The interesting question for theory to answer is whether encouraging equipment investment can have much effect on industrialization. In our model, relatively low equipment prices will increase the spread of advanced techniques. However, our discussion indicated that a subsidy to equipment is likely to be dominated by alternative policies, including a direct subsidy to output in the modern sector. If there are multiple equilibria, such a policy may be more likely to encourage a shift to a 'good' equilibrium.

Conventionally, the advocacy of policy interventions to encourage investment should rest on a demonstration that social returns differ from private ones. Given that the relationship identified by De Long and Summers may be the outcome of industrialization, the size of the equipment investment coefficient cannot be taken as evidence for important externalities. Overall, it seems likely that other policies, notably those towards encouraging human capital accumulation or the adoption of foreign technology, may be rather more important to generating growth and structural change.

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