The Determinants of Technological Capability: A Cross-country Analysis

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ABSTRACT *Existing studies aimed at explaining cross-country differences in technological capabilities among developing countries have tended to use crude and unrealistic proxies—such as expenditure on R&D or the number of registered patents—which bear little or no relation to the findings from firm-level studies. This paper introduces a more realistic measure of technological capability based on an index developed by UNIDO, which is related to the complexity involved in the manufacture of engineering goods. The significance of this measure derives from the fact that in developing countries, the mastery of known technologies is far more important than the ability to generate new technologies through formal R&D. A regression analysis carried out with this measure points to the significance of market size, the stock of scientists and engineers and trade policy orientation as important determinants of cross-country differences in this measure of production capability.*

1. Introduction

In the literature on technological capabilities there is a rather marked lack of coherence between the different levels of analysis. At the micro level, where most of the literature is in fact concentrated, detailed case-studies have revealed that a variety of different types of capabilities can be acquired by firms in developing countries and from this literature one can also gain important insights into the often subtle processes that contribute to the accumulation of these various capabilities.[1] Pressures to engage in technological effort can emanate first of all from the economic environment within which firms operate. The most important of these appear to be the general economic climate, the degree of competition and (related to it) market structure, the rate of change of the international technological frontier, various government policies aimed at regulating foreign trade and fiscal and monetary parameters, and government investments in a supportive science and technology infrastructure through public R&D and technical education of the labour force. In addition, there are important factors within individual firms which lead them to engage in capability building. The nature of ownership, firm size, attitudinal/personal factors and the nature of the technology employed are elements that have been mentioned frequently in the literature. Some of

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these studies also contain a very rich analysis of the intricate interactions among the many different features that shape this learning process. Reviewing the literature, Bell (1984) designed a classification with no less than six different (interactive) mechanisms of firm-level technological learning. These include: experience-based learning-by-operating; learning through changing products, processes or production organization; learning through performance monitoring; learning through staff training; learning through acquisition of external expertise; and learning through search for new technological knowledge outside the firm. While most of the insights have come from qualitative research, recently some studies have also attempted to undertake quantitative measurement and econometric testing of the observed relationships.[2]

At the country level one also finds econometric analysis attempting to explain the emergence of capabilities, but most such exercises rely on crude proxy measures which bear little or no relation to what has been learned at the firm level. Even though efforts to develop measurable macro-economic science and technology indicators have been ongoing since the 1970s, the results up to now have been rather disappointing (Bhalla, 1996). For example, the use of the number of patents in some of these studies[3] has only limited appeal, given the fact that technological efforts in most developing countries are still predominantly aimed at mastering already existing imported technologies, a point amply documented in the firm-level case studies. Such mastery may possibly entail making minor adaptations to make technologies more suitable for local use, but the effort that this entails is still very far removed from the kind of fundamentally innovative research that could possibly lead to new patents. In other cases, 'input' measures, such as R&D expenditure, number of scientists and education levels, have been used as proxies for capability, when in fact they should be used instead as explanatory variables. Yet other studies have opted to use an impact measure, namely, productivity (Pietrobelli, 1994). However, this is also an unsatisfactory proxy because productivity increases can be taken as evidence of accumulated technical knowledge only if other sources of improvement that have nothing to do with capability building—such as increased capacity utilization or straightforward investment in more efficient technology—can be ruled out, which is not usually the case.[4]

Our intention here is to fill this void in the literature by conducting a cross-country comparison of technological capabilities using a measure that is much more firmly rooted in the micro-foundations of the concept than the indicators used previously. For this purpose we develop a capability indicator based on a dataset furnished by UNIDO in its Global Reports 1989/90 and 1990/91.[5] This is described in Section 2 below. The various explanatory variables to be used in the data analysis are introduced in Section 3. The data analysis itself consists of a set of simple least squares linear regressions, the results of which are reported in Section 4. Conclusions are drawn in Section 5.

2. Technological Complexity

It should be emphasized at the outset that any exercise designed to measure technological capability is necessarily somewhat modest in scope. Since there are known to be numerous dimensions of technological capability,[6] no single indicator can claim to encompass the measurement of all of them. Also, it is quite clear from detailed micro-economic case studies that capabilities tend to be somewhat idiosyncratic, shaped as they are by the complex interplay of a country's history, economic policies, institutional environment and resource endowments. No simple quantitative measure can hope to capture the subtle differences in competitive advantage that emanate from such specificities. However, even in the presence of such constraints, it is apparent that some measures are more appropriate than others as a basis for comparing technological capabilities between developing countries. In particular, mention has already been made of the fact that for much of the Third World, the mastery of known technologies is far more important than the ability to generate entirely new technologies. Hence, a measure based on *production* capabilities is much preferable to, for example, a measure capturing innovative performance.

Of the various types of production capabilities, the ability of a developing country to produce engineering goods is especially important, partly because these require metal processing and metal fabricating skills that are fundamental in manufacturing as a whole. The engineering sector typically also functions as a training ground for a broad spectrum of managerial and entrepreneurial skills that are useful in a range of other industries (James, 1991). Moreover, the sector often plays a crucial role in the assimilation of foreign technology. It is here that foreign prototypes are studied and reproduced and where minor adaptations are often also carried out to make the technology more suitable for local conditions faced by users. Since many engineering products are capital goods, such activities are crucial for the industrialization process as a whole through their beneficial impact on productivity and innovation in user-industries. As Rosenberg has pointed out, countries that do not have a local capital goods sector tend to lack the "technological base of skills, knowledge, facilities and organisation upon which technical progress so largely depends" (1963, p. 223). Because it is based on skills and knowledge needed for the manufacture of engineering goods, the measure of technological capabilities that we use below is thus particularly relevant to developing countries.[7] Specifically, we shall rely on elements of a "technological complexity index" that UNIDO has developed by breaking down

> a particular finished capital good[8] into all its constituent parts, each of which undergoes a series of separate production processes before they are put together with the components purchased externally at the final assembly stage. The detailed list of parts and components so identified receives expert appraisal as to their levels of difficulty in manufacturing, on the basis of the particular set of production processes involved and the degree of skill needed in the production processes to obtain an output of standard quality. (UNIDO, 1990, p. 34)

UNIDO has measured the level of skills required for no less than 145 sub-products in the machinery, equipment and other types of metalworking industry using this methodology.[9] Such information can be used to assess the prevailing level of engineering skills and knowledge in the metalworking sector of a given country when there is information about the nature of the goods which it makes. Such data are provided for 79 developing countries in the UNIDO Global Report 1990/91.

The skill and knowledge scores assigned by UNIDO to each engineering product were used by us to construct a complexity indicator for each country. For this purpose, it is realistic to assume that the skills required for successively more complex products presuppose, or embrace, those required for less complex ones (that is, that overall skill requirements are not additive). Thus, what matters is not so much the diversity of the engineering goods produced in any given country but rather the complexity of its most complex product(s).[10] Accordingly, the dependent variable in the empirical analysis is defined as the score assigned by UNIDO to the most complex good produced in each of the 49 countries contained in our sample.[11] Column 2 in Table 1 shows the values taken by this 'Technological Complexity Indicator' (TCI).

Our indicator has certain shortcomings. In particular, it is somewhat peculiar that

Table 1. Distribution of sample by most complex engineering goods produced, technological complexity indicator (TCI), and economies of scale estimates

	No. of countries	TCI	Economies of scale (% cost increase below MES)
Commercial planes	2	201	> 20% at $\frac{1}{2}$ MES
Passenger cars, produced	2	167	> 10–15% at $\frac{1}{3}$ MES
Tankers, launched	6	164	Large (unspecified)
Sea-going merchant vessels	14	136	Large (unspecified)
Motor vehicle engines, diesel	1	108	10% at $\frac{1}{2}$ MES
Watches	1	106	Large (unspecified)
Bulldozers	1	99	Not available
Electric motors, 1 HP and over	1	95	15% at $\frac{1}{2}$ MES
Tractors of 10 HP and over	1	91	6.0–7.7% at $\frac{1}{2}$ MES
Industrial scales	1	86	8% at $\frac{1}{2}$ MES
Television receivers	5	85	15% at $\frac{1}{3}$ MES
Passenger cars, assembly	1	83	Not available
Motor cycles, scooters, etc.	2	79	Slight (unspecified)
Radio receivers	2	54	Not available
Refrigerators, domestic	2	53	6.5% at $\frac{1}{3}$ MES
Accumulators for motor vehicles	2	51	Not available
Electric lamps	1	45	Not available
Nails, screws, nuts, bolts, rivets	2	42	Not available
Batteries and cells, primary	2	40	4.6% at $\frac{1}{3}$ MES
Total no. of countries:	49		

Sources: Pratten (1988) and UNIDO (1990).
Note: MES, minimum efficient scale of production—the scale at which unit costs cease to fall.

no electronics products aside from electronic tubes appear to have been included in the list of engineering products used by UNIDO. It is possible that the exclusion of such recent products results, to some extent, in an underestimation of the true value of the complexity indicator for countries such as South Korea and Malaysia which began to produce a range of consumer electronics in the 1980s. However, since the manufacturing complexity of these products was not very high in 1987, we believe that this problem is unlikely to exert a major effect on our analysis and that our indicator is at present the best available proxy to measure manufacturing complexity.[12]

3. The Explanatory Variables

We hypothesize that variations in the degree of technological complexity thus defined between countries can be explained by three kinds of variables, namely those that influence the demand side of the economy, those that bear on supply factors and those that reflect government policy towards the engineering sector itself.

3.1 Demand-side Variables

Market size is used as our main demand-side variable for two interrelated reasons. The first is that technological complexity is closely related to economies of scale and the second is that the latter depend heavily on market size. The first relationship—between complexity and scale—has been clearly stated by Pratten in the following terms.

> Aircraft, cars and lorries are products for which there are large economies of scale. One explanation is the complexity of these products, they are made up of many distinct parts. Also many of the parts have to be made very accurately. Complexity affects design, development and production costs. Similarly where a series of complex manufacturing operations are required to produce products as in oil refining, there will tend to be large economies of scale. Where production processes are simple as for the production of many items of food, the economies of scale for production are smaller. (Pratten, 1988, p. 35)

Table 1 attempts to provide some evidence in support of this point of view for the most complex products that are manufactured by the countries in our sample. These range from planes and passenger cars at the one extreme, to nails and lamps at the other. It is clear from the estimates for the very highly complex products shown in Table 1, that their production process exhibits highly pronounced economies of scale (see column 4). Due to the lack of available estimates for the majority of the less complex products, however, we are unable to confirm the absence of such economies at the other end of the spectrum, though the few cases that can be documented do tend to point in this direction.

To the extent that economies of scale influence the most complex item that a country is capable of producing, then so too must market size since it is this that largely determines the degree to which large-scale production is economically feasible. In theory, of course, relatively small countries can use exports to overcome the constraints imposed by the size of the local market. In practice, however, for reasons that have to do with uncertainty on the one hand and the need for local learning on the other, production for the home market typically precedes exporting. It has been argued that this can create significant entry barriers for countries with small domestic markets, with respect to those engineering goods industries which exhibit pronounced economies of scale (Forsyth, 1990, p. 39). This point is supported empirically by a recent major comparative study of the national innovation systems in a number of developed and newly industrializing countries, which concludes that " ... countries with large affluent populations can provide a protected market for a wide variety of manufacturing industries and may engage in other activities that 'small' countries cannot pursue, at least with any degree of success ..." (Nelson, 1993, p. 507).

In the empirical analysis, therefore, the size of the domestic market is used to capture the demand-side influence on technological complexity. It is measured in two ways. One is the total GDP and the other is a decomposition of this total amount into its components, namely, population and GDP per head (each of which captures a different dimension of market size).

3.2 Supply-side Variables

In the literature on technological capabilities, the supply-side is usually captured by measures of 'human capital', such as enrolments in education of different kinds and levels, government expenditure on education and the number of scientists and engineers. Of these alternatives, the last appears to be the most suitable for explaining differences in the technological complexity of production between countries, since it is likely to be at this skill level, rather than lower levels, that a country encounters barriers to the production of increasingly more complex engineering goods. Our hypothesis is that complexity in this sense will vary directly with the available number of scientists and engineers. To some extent, of course, all the supply-side indicators mentioned above are themselves a function of a country's GDP, inasmuch as the latter determines the resources that are available for investment in human capital. In this role, the GDP exerts an influence that is additional to, and in the same direction as, its (demand-side) function of being an indicator of market size.

In addition to scientists and engineers, other resources such as finance and managerial expertise are also likely to be important. Since many of these additional resources are likely to be supplied by multinational corporations, foreign direct investment is included as a separate explanatory variable.

3.3 Policy Variables

Ideally, one would like to capture all the policy influences on the development of the engineering goods sector. These would include not just a country's explicit science and technology policies (such as the establishment of specific institutions or the deliberate promotion of certain specific sectors), but also the general economic policies (especially industrial and trade policies) that bear indirectly on the complexity of the engineering goods that a country is able to produce. In practice, however, differences between countries in these respects are extremely difficult to quantify. Several different indicators of trade policy orientation and/or extent of price distortions have been used in studies attempting to explain cross-country differences in economic growth, but all of them are to some extent inadequate.[13]

From among the available indicators two measures appeared to be most suitable. The first is the trade orientation index presented by the World Bank (*World Development Report*, 1987), which has been widely used in studies attempting to explain inter-country variations in growth performance.[14] This indicator purports to measure the degree to which a country's trade orientation can be described as inward or outward-looking, where the distinction between the two is defined with reference to effective rates of protection, the use of direct controls, export incentives and exchange rate overvaluation.[15] The index used is for the period 1973–85, which just precedes the year (1987) to which the data for the complexity indicator pertain. The advantage of this indicator is that it captures trade orientation differences between countries over a rather extended time period rather than in a single year. It would be reasonable to assume that trade orientation is unlikely to have a significant effect on technological learning unless the same trade regime is maintained for at least a decade.

As a second indicator of trade regime, use is made of a much narrower proxy of inward versus outward orientation, namely the average 1985 nominal tariff rate pertaining specifically to machinery and equipment given in Erzan *et al.* (1989). To our knowledge, this is the best information available on the extent of protection of machinery and equipment in the mid-1980s. The data do not include the effects of non-tariff barriers (which tend to be very specific and the protective impact of which is extremely hard to estimate), but they do include—aside from the regular customs and fiscal duties—various so-called 'para-tariffs' such as customs surcharges and surtaxes, stamp taxes, additional fiscal charges and taxes on foreign exchange transactions (Erzan *et al.*, 1989, p. 33).

What is not clear on *a priori* grounds, though, is *how* a country's trade strategy—whether it be inward- or outward-looking—is likely to bear on the complexity of its engineering sector. Indeed, in the literature on technological capabilities, even though most authors recognize the importance of this relationship, there is no agreement among them over the causal connections that define it. On the one hand, following the neo-classical tradition in trade theory, it could be argued that an outward-looking trade regime enables the producers of engineering goods to be relatively well acquainted with the availability and absorption of new technologies. It could also be argued that international competition provides firms with the incentives that are needed to adopt and foster these technologies.

Advocates of import-substituting industrialization, on the other hand, contend that learning-by-doing is the most important vehicle through which advancement of the engineering sector is likely to occur and typically suggest that at least some initial protection is needed for this purpose. A case can thus also be made that countries with inward- rather than outward-looking trade strategies will tend to exhibit technologically more complex engineering sectors and the issue thus needs to be resolved empirically.

4. Results

Data limitations dictated the number of countries available for use in the cross-country regression analysis. For the demand and supply-side variables, there is information for 49 of the 79 developing countries for which UNIDO has compiled the product complexity indices introduced earlier. For the World Bank policy variable the sample was restricted to 28 such countries, whereas for the policy variable based on the average equipment tariff rates the number of countries was 27. As already explained, the TCI relates to 1987. So do the figures for GDP, GDP per capita and population. In view of the paucity of data on the number of scientists and engineers, information for a range of years around 1987 is used. Two different measures were employed, namely the absolute numbers of scientists and engineers and the total number as a percentage of total population. Three different proxies covered foreign direct investment, namely total inward stock by the end of 1985, average annual inward flows during 1980–85 and the average annual flows as a percentage of gross capital formation. The complete data set is contained in the Appendix.[16]

Table 2 contains the OLS estimation results for the 49-country sample (*t*-values in parentheses). In all the equations reported in this section the semi-loglinear functional form was found to give the best fit. All regressions satisfy the usual conditions of normality and homoscedasticity.

In equations (1) and (2) the effect of the market size variable on technological complexity is assessed, measured respectively by GDP (equation (1)) and population size and per capita income (equation (2)).[17] The fit of these two regressions is reasonably good, with a total explained variation of over 50% in both cases, and there is a significant positive relationship between technological complexity as defined above and the GDP measure of market size. As might also have been expected, it is not just the population component of the GDP that influences this result: equation (2) indicates that per capita income exerts an independent influence on a country's technological capability. An examination of the standardized regression coefficients (beta coefficients) for the two components of market size reveals them to be roughly equal in importance. The beta coefficient for the population variable is 0.70, only slightly higher than the corresponding coefficient for GDP per capita, which is 0.62.[18]

The third and fourth equations report the effects of scientists and engineers and foreign direct investment on the dependent variable. All explanatory variables in these regressions are absolute magnitudes, since none of the percentage indicators were found to correlate significantly with the TCI variable. It thus seems that absolute amounts of resources rather than percentage values determine manufacturing complexity of engineering products. Further, the total stock of foreign direct investment

Table 2. Regression results—49-country sample

Equation no.	Adj. R^2	F	Standard error	GDP	GDPCAP	POP	SANDE	FDISTOCK	Const.
(1)	0.53	54.25	32.83	20.89					−84.69
				(7.365**)					(−3.116**)
(2)	0.53	28.47	32.55		25.30	19.59			−72.62
					(5.84**)	(6.58**)			(−2.55*)
(3)	0.51	50.93	33.38				15.43		−50.02
							(7.14**)		(−2.15*)
(4)	0.54	28.62	32.51				13.02	4.68	−52.81
							(5.28**)	(1.88*)	(−2.33*)
(5)	0.55	30.12	32.05	12.26			7.49		−82.16
				(2.23*)			(1.82*)		(−3.10**)
(6)	0.56	21.51	31.56		16.58	10.11	8.08		−68.27
					(2.73)**	(1.81*)	(1.99*)		(−2.47**)

Note: All explanatory variables in logarithms. GDP is total gross domestic product, GDPCAP is gross domestic product per capita, POP is population size, SANDE is the absolute number of scientists and engineers and FDISTOCK is the absolute stock of inward foreign direct investment. For data sources see the Appendix.
*Significance at the 95% level of confidence and ** significance at the 99% level.

performed consistently better than the flow variable, which is why we have only reported the former.

The correlation coefficient between the two independent variables is on the high side ($r = 0.53$), indicating some problems with multicollinearity. Therefore we first regressed the two independent variables on their own. Although foreign direct investment on its own has a significant effect on the measure of technological complexity, its explanatory power is quite low (adj. $R^2 = 0.21$). The result is therefore not reported in the table. In contrast, the number of scientists and engineers on their own explains more than half of the variation in the dependent variable, as shown by regression equation (3). The result of the regression with both independent variables, reported in equation (4), is only slightly better than the result obtained in regression (3), with a *t*-value of the foreign direct investment variable of only 1.88. We conclude that the number of scientists and engineers is the main influence on the supply side.[19] Considering the weak data for this variable, its explanatory power is in fact remarkably good. Hence subsequent analysis of the supply side is based on this variable alone.

An attempt to gain insight into the relative importance of the demand and supply-side variables was made by regressing them together in one equation. In this way it is possible to assess whether the regressions suffer from a serious omitted variables problem. Joint regression (5) in Table 2 uses GDP as the demand variable, while regression (6) uses GDP per capita and population. The results are very similar. The total explained variation is not much higher than in the first four regressions, reflecting a problem with multicollinearity between the demand and supply variables. The estimates of the individual coefficients are therefore not very accurate. Nevertheless, even though the *t*-values of all variables are lower than in the earlier regressions, demand and supply variables both retain significance in these combined regressions. This means that the multicollinearity problem is not so serious as to mix up completely the effects of the individual explanatory variables.

The combined regressions indeed suggest a problem with omitted variables in the single regressions, as shown by the fact that the coefficients in the single regressions are much higher than in the combined ones. In the demand equations part of the effect of scientists and engineers on capability is wrongly ascribed to the demand variables, and vice versa in the supply equation. Insight about the relative effects of demand and supply can be derived from the standardized regression coefficients (beta coefficients). In the case of regression (4), the beta coefficient for scientists and engineers is 0.35 and the coefficient for GDP is 0.43. Since the one coefficient is not clearly much larger than the other our results suggests that the demand and supply influences are roughly equal in importance. The same conclusion results from an examination of the beta coefficients in regression (5), which are 0.38 for scientists and engineers, 0.41 for GDP per capita and 0.36 for population size. We conclude that the demand and supply variables are both important for the enhancement of a country's engineering capability (as measured by our complexity indicator). Also, the results suggest that countries which are constrained by a small market size may to some extent be able to compensate for this drawback by putting more emphasis on raising their stock of scientists and engineers.

Results based on the smaller sample of 28 countries, which include the influence of trade policy on technological complexity as measured by the World Bank variable, are reported in Table 3. Dummy variables were assigned to countries that are described by the World Bank as being strongly-outward oriented or strongly-inward oriented over the period 1973–85 (represented, respectively, by STR_OUT and STR_IN in the equations in Table 3). We did not distinguish between two other categories mentioned in the World Bank report, namely moderately inward and moderately outward, because the distinction between these two was not clear-cut in all cases. The report itself admitted that there may be scope for disagreement over these two intermediate subgroups. The countries classified into the two extreme categories are, however, much less likely to suffer from such ambiguity.

Aside from the presence of the two trade-strategy dummies, the equations in Table 3 use the same variables as the first three equations reported in Table 2.[20] It can be seen that the overall fit of these three regressions does improve. However, significance of the dummies is found only with respect to the strongly-inward orientation in the third equation at the 95% level, while this variable is just slightly below the 95% level in the first equation.[21] Interestingly, the results do not support the contention that strong outward orientation would promote the mastery of technologically complex engineering activities, although it remains possible that the lack of significance in this respect has more to do with the fact that there are only three strongly outward-oriented countries in the sample.

On the other hand, the significantly negative effect of the STR_IN dummy in regression (3) and (almost) in regression (1), indicates that this type of trade policy tends to hinder rather than promote the attainment of higher levels of technological complexity by the (limited number of) countries in the sample. The significance of the variable in regression (3) suggests that such a strategy is accompanied by a less effective utilization of a given stock of scientists and engineers. This tends to corroborate the findings about the influence of the policy incentive climate on capability building in the firm-level capability literature. Generally, protection of domestic industry is unlikely to induce much technological learning when pressures for performance improvement are completely removed, as would happen when large firms with considerable domestic market power are comfortably insulated from foreign competition in the home market. Even when technological efforts are indeed undertaken in such a setting, these are likely to involve a significant element of "reinventing the wheel" because information about foreign technologies which could serve as a basis for learning is hard to obtain in the face of pervasive import restrictions on such technologies (see, for example, Lall, 1987).

One should be careful, however, with the interpretation of this finding. It would be incorrect to infer that the engineering sector would not require protection in order for technological learning to occur and technological capabilities to be acquired. For, by inspecting the individual countries that deviate most sharply from the fitted regression line (in both directions), one can see, first of all, that not all cases in the strongly inward category perform poorly. Argentina, for example, belongs in the group and yet has attained a greater than predicted degree of technological complexity. On the other hand, most of the countries that perform substantially *worse* than predicted by the regressions are drawn from a single region, Africa, where a somewhat specific set of factors has hindered the process by which technological capabilities are acquired. In particular, the industrial sector in the region is dominated by state-owned enterprises that have paid very little attention to technological issues in general and technological capabilities in particular (James, 1995). They have focused instead on the maximization of output and foreign exchange. In short, our results seem to say more about the manner in which inward- orientation has been practised in different developing countries, than about the strategy *per se*.

The results of the regressions performed on the sample of 27 countries including the tariff variable as a measure of protection (TARIFFS) appear in Table 4. It can be seen that the effect is quite insignificant in all three regressions. Moreover, the first two regressions also exhibit problems with multicollinearity and normality.

Table 3. Regression results—28-country sample

Equation no.	Adj R^2	F	Standard error	GDP	GDPCAP	POP	SANDE	STR_OUT	STR_IN	Const.
(1)	0.70	21.77	26.15	27.16				9.90	−22.14	−138.82
				(6.69**)				(0.59)	(−2.05)	(−3.29**)
(2)	0.69	16.01	26.48		30.47	26.25		2.74	−19.92	−129.39
					(4.55**)	(6.03**)		(0.13)	(−1.73)	(−2.86**)
(3)	0.61	14.88	29.83				16.94	29.57	−26.49	−55.93
							(5.37**)	(1.56)	(−2.17*)	(−1.50)

Note: STR_IN, dummy for strong inward orientation; STR_OUT, dummy for strong outward orientation (*World Development Report*, 1987). For other notes see Table 2.

Table 4. Regressions results—27-country sample

Equation no.	Adj. R^2	F	Standard error	GDP	GDPCAP	POP	SANDE	TARIFFS	Const.
(1)	0.51	14.56	31.28	19.36				0.12	−65.98
				(4.696**)				(0.333)	(−1.812)
(2)	0.50	9.65	31.64		23.01	18.11		0.31	−61.01
					(3.404**)	(3.981**)		(0.671)	(−1.626)
(3)	0.48	13.12	32.17				13.37	0.22	−27.32
							(4.423**)	(0.582)	(−0.901)

Note: TARIFFS are average nominal tariff and para-tariff rates for machinery and equipment, 1985 (Erzan *et al.*, 1985). For other notes see Table 2.

This lack of any significant effect does not necessarily weaken the conclusions based on the regressions with the World Bank trade indicator reported above. More likely, measurement problems distort the results. We suspect that our TARIFFS indicator may be too limited a proxy for the measurement of trade orientation. One obvious weakness of the data is that they pertain to a single year, whereas one may reasonably expect high values on our complexity index to reflect extended periods of learning. Thus, our TARIFFS indicator could be quite biased for those countries that undertook extensive liberalization in the early 1980s, while their engineering sectors were built up during an earlier period of high protection. Another problem with the TARIFFS variable is that it is based on nominal rather than effective protection rates and we know that differences between these two rates can be quite substantial.

5. Conclusions

Quantitative comparisons of technological capabilities between developing countries do exist. However, the commonly used measurement indicators are generally very crude and bear little or no relation to the firm-level literature. In this paper use has been made of a more sophisticated indicator of technological capabilities as a basis for cross-country analysis. This is based on the skills required in the production of the most complex engineering good produced by each of the countries in our sample.

We began by examining the demand and supply-side determinants of capability. The significance of the demand-side variables (per capita income and population size) confirms our expectation that developing countries with relatively small markets face particular difficulties in building up their technological capabilities and most likely also in improving their rates of economic growth. In addition, factors affecting the supply of resources required for technological capability building were found to have a significant effect, especially the number of scientists and engineers. The fact that the variable retains its significance in estimated equations which also include proxies for market size suggests that countries with a small market can to some extent use supply-side variables to compensate in part for the difficulties they confront on the demand side.

When the influence of trade policy was examined outward trade orientation was not found to have a statistically significant impact on the acquisition of higher level technological capability, but a strongly inward orientation exerted a negative influence on that process, especially in sub-Saharan Africa. Because this influence does not apply uniformly to all countries in the strongly inward-looking category, however, we suspect that what matters is not so much any intrinsic weakness of the strategy, but rather the way in which it has been implemented in different countries. A strongly inward-oriented trade strategy may lead to technological isolation and overprotection, even though it exerts only an indirect influence on the process of capability building. In practice there is a range of policies that can be used which have a more direct effect on the process, which may be able to offset to some extent such potential disadvantages. In sub-Saharan Africa, for example, there is much more that could be done to favour local producers of engineering goods in the design of foreign aid projects and state procurement procedures. There is also considerable scope for institutions designed specifically to promote the acquisition of domestic technological capabilities, such as industrial extension services, technological advisory units and international information networks (Forsyth, 1990).

Notes

1. See mainly Katz (1978), Lall (1987), Amsden (1989), Westphal *et al.* (1984), Fransman & King (1984) and Stewart *et al.* (1992).
2. See Deraniyagala (1994), Romijn (1996) and Wignaraja (1995) for recent efforts in quantification and empirical testing.
3. See, for example, Teitel (1994a, b).
4. For a discussion of these problems see Bell *et al.* (1984).
5. UNIDO itself has also undertaken some limited empirical analysis with its own data (*Global Report 1989/90*, pp. 131–132), but there is clearly scope for more work in this area. The UNIDO analysis included different explanatory variables from the ones used in this study and suffered from a number of statistical problems. Among other things, no tests for multicollinearity and heteroscedasiticity were apparently carried out, the direction of the causality was problematic in some cases, a comparison of the relative impact of the different explanatory variables was made on the basis of the actual regression coefficients instead of normalized coefficients, and the choice of some of the explanatory variables (such as market size) was not well motivated.
6. See, for example, Lall (1992), for a detailed classification. He distinguishes pre-investment, project execution, process engineering, product engineering, industrial engineering and linkage capabilities. Within each of these categories he makes a further distinction between simple, routine (experience-based) operations, adaptive (search-based) operations and innovative (research-based) efforts.
7. Because of its emphasis on skills and human capital formation our measure of capability also accords with the prominent role assigned to these factors in recent theories of endogenous growth (see, for example, Lucas, 1988, and Romer, 1990, 1993).
8. UNIDO refers consistently to "capital goods" rather than "engineering goods" in the discussion of its index. However, the data base used for the construction of its index covers all major products in division 38 of the International Standard Industrial Classification, which also includes several consumer products. Division 38 is subdivided into five major groups. Three of them, i.e. non-electrical machinery, electrical machinery and transport equipment, are mainly capital goods producing branches. The other two are fabricated metal products and professional instruments. Hence, we prefer to use the term engineering goods rather than capital goods in this paper.
9. The list of 145 engineering goods used in this paper constitutes a sample which is representative of the diversity and complexity of the industry according to UNIDO. This sample covers all major engineering goods in ISIC 38 at the six-digit level of disaggregation. The full list of engineering goods assessed by UNIDO covers more than 1100 items.
10. It is not implausible to argue that countries that make a whole range of complex goods have more production capability than countries that produce just one complex item. However, in order to keep the measurement relatively simple and straightforward we have chosen not to take this distinction into account in our complexity indicator. The production of a relatively large range of items would presumably require a relatively complex production organization in a country's local engineering sector, but it would not require the mastery of more complex operations in a purely engineering sense. For the same reason inter-country differences in production volume are also not taken into account. One could argue that countries which produce an item in high volumes would require a more complex production organization and hence would have a higher level of capability. However, differences in production volume are less relevant when we focus on capability in terms of purely engineering complexity.
11. There are only 49 countries in our sample because a full set of explanatory variables could not be obtained for 30 countries. Initially we also constructed an alternative capability indicator based on the unweighted average score of a country's three most complex products. The use of such an average-based indicator makes sense if the skills and knowledge involved in the production of the more complex engineering goods in a country are not completely additive, so that some allowance has to be made for the diversity of engineering goods production. However, this alternative indicator has not been used in this paper because the results of the data analysis using this indicator were in fact very similar to the results using the indicator based on the score for the one most complex engineering good. Since the results obtained with the indicator based on the single most complex engineering good were overall slightly better, we did not consider it worthwhile to report the results based on the average-based indicator. One obvious problem with using an average-based indicator more-

over is that the number of scores to be averaged is chosen arbitrarily. However, at the same time the similarity in results is reassuring since it indicates that our results have some stability.

12. One can think of other possible indicators of the extent of technological development of the engineering sector, such as some measure of the sector's size or export-orientation, but these are only imperfect proxies of technological production capability.
13. For a review, see Rodrik (1995, pp. 2938–2941).
14. See, for example, Greenaway & Nam (1988), Alam (1991), Easterly (1992) and Das (1990).
15. Countries were classified somewhat subjectively, by combining information about these four indicators. No formal mathematical procedure could be applied since some of the indicators are qualitative.
16. The data set does not contain those explanatory variables which turned out to be insignificant in the regression analysis.
17. Use of the latter definition of market size is justified when, as here, the two separate components of the GDP are not closely correlated.
18. However, the causality in the relationship between GDP (or GDP per capita) and complexity in the manufacture of engineering goods may not be entirely unidirectional. It is possible that increasing technological advancement in a country's engineering sector would to some extent contribute to the achievement of a higher GDP. We attempted to conduct a Granger causality test between our capability indicator and GDP per capita, but this attempt had to be abandoned because we did not succeed in constructing a good quality data set including lagged values of both variables.
19. However, one may argue that the causality also runs to some extent from technological complexity to scientists and engineers because the manufacture of higher-complexity engineering goods would call for more manpower with high-level engineering expertise. Therefore we carried out a Granger causality test (see, for example, Gujarati, 1988, pp. 542–543) using lagged data for both variables pertaining to the early 1970s (the UNIDO Global Report 90/91 gives data about the range of engineering goods produced in 1973 as well as 1987). However, due to the scarcity of data about numbers of scientists and engineers the number of observations included in the test regressions was only 26. In spite of the small data-set the test results clearly showed one-way causality from scientists and engineers (SANDE) to manufacturing complexity (TCI), as shown by the significance of the regression coefficient relating to SANDE in the first regression and the non-significance of the coefficient relating to TCI in the second regression reported below. This result supports the inclusion of the number of scientists and engineers as an explanatory variable in our analysis. The regression results were as follows (t-values between parentheses):

(1) $TCI_{1987} = \underset{(1.791)}{0.2815}\ TCI_{1973} + \underset{(2.174)}{9.6882}\ SANDE_{1973} + \underset{(0.013)}{0.4642}$

Adj.$R^2 = 0.54$ $F = 15.80$

(2) $SANDE_{1987} = \underset{(0.205)}{0.00076}\ TCI_{1973} + \underset{(8.889)}{0.9528}\ SANDE_{1973} + \underset{(1.520)}{1.2822}$

Adj.$R^2 = 0.88$ $F = 93.92$

20. Joint demand-supply equations with the trade dummies added were also estimated, but the results of these were unsatisfactory and have therefore not been reported in the table. In particular, the scientists and engineers variable becomes insignificant in these regressions. However, we suspect that this is due to the small sample size, and it would thus be imprudent to derive an economic conclusion from this result. At the same time it is noteworthy that the results with respect to the trade dummies in these joint regressions are quite similar to the ones reported in the single equations in Table 4: STR_IN is significant at the 95% confidence level ($t = -2.074$; two-sided test) in the regression with the GDP and SANDE variables, and close to significance ($t = -1.761$) in the regression with the GDPCAP, POP and SANDE variables), while STR_OUT is quite insignificant in both regressions.
21. The improved fit as compared to the equations fitted for the 49-country sample seems to have more to do with the fact that there were several oil exporting countries in this sample which were not present in the 28-country sample. Compared to non-oil exporters, these countries tend to have a high GDP per capita in relation to the technological complexity of their engineering products.

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Appendix. The Dataset

Country	(TCI)	GDP (in million US$, 1987)	Population (in thousands, 1987)	GDP per capita (in thousands of US$, 1987)	No. of scientists and engineers (year)	Foreign direct investment inward stock (millionUS$)	Nominal protection on machinery and equipment (%), 1985 (Erzan *et al.*)	Trade orientation (WB measure) 1973–85
Nepal	40	2715	17 357	0.15	3668 (1980)	2	n.a.	n.a.
Belize	40	277	175	1.58	419 (1970)	10	21	n.a.
Haiti	42	1968	6113	0.32	14 189 (1982)	112	n.a.	n.a.
Ethiopia	42	5409	43 463	0.12	47 113 (1984)	114	n.a.	Strongly inward
Jordan	51	6166	4005	1.54	30 205 (1986)	455	n.a.	n.a.
Malawi	54	1228	7499	0.16	3981 (1977)	138	n.a.	n.a.
Bolivia	45	4953	6157	0.80	64 300 (1992)	592	20	Strongly inward
Rwanda	54	2152	6425	0.33	1762 (1978)	133	n.s.	n.a.
Barbados	51	1449	254	5.70	1163 (1970)	123	15	n.a.
Mauritius	136	1831	1004	1.82	7256 (1983)	37	n.a.	n.a.
Kenya	136	7971	22 936	0.35	16 241 (1982)	368	n.a.	Moderately inward
Guyana	136	349	793	0.44	969 (1982)	14	15	n.a.
Togo	79	1232	3217	0.38	461 (1971)	216	n.a.	n.a.
Kuwait	136	20 513	1877	10.93	60 398 (1985)	342	4	n.a.
Jamaica	85	2982	2350	1.27	5963 (1970)	458	15	n.a.
Cameroon	79	13 326	10 822	1.23	11 785 (1976)	1125	n.a.	Moderately inward
Sudan	53	10 886	23 517	0.44	9708 (1971)	28	41	Strongly inward
Dom. Republic	53	5081	6716	0.76	7837 (1970)	265	n.a.	Strongly inward
El Salvador	85	4628	5054	0.92	5489 (1974)	181	n.a.	Moderately inward
Ghana	85	4853	13 391	0.36	6897 (1970)	312	31	Strongly inward
Trinidad and Tobago	85	4798	1212	3.96	3314 (1970)	1719	15	n.a.
Zambia	83	2423	7365	0.33	11 000 (1973)	99	n.a.	Strongly inward
Cyprus	86	3701	680	5.44	23 222 (1987)	520	17	n.a.
Bangladesh	164	19 294	102 563	0.19	23 500 (1973)	112	67	Strongly inward
Singapore	164	20 245	2554	7.93	38 259 (1980)	13 016	0	Strongly outward
Iraq	91	57 558	16 330	3.52	43 645 (1972)	149	n.a.	n.a.

Appendix *continued*

Country	(TCI)	GDP (in million US$, 1987)	Population (in thousands, 1987)	GDP per capita (in thousands of US$, 1987)	No. of scientists and engineers (year)	Foreign direct investment inward stock (million US$)	Nominal protection on machinery and equipment (%), 1985 (Erzan *et al.*)	Trade orientation (WB measure) 1973–85
Malaysia	136	31 602	16 526	1.91	26 000 (1982)	8510	11	Moderately outward
Nigeria	85	27 113	101 408	0.27	22 050 (1980)	4405	28	Strongly inward
Hong Kong	164	47 139	5581	8.45	145 523 (1986)	3520	n.a.	Strongly outward
Thailand	136	50 535	53 427	0.95	20 288 (1975)	1999	33	Moderately outward
Venezuela	164	48 029	17 974	2.67	942 972 (1991)	1548	18	n.a.
Pakistan	136	38 818	102 238	0.38	287 000 (1990)	1079	62	Moderately inward
Sri Lanka	106	6413	16 361	0.39	21 533 (1985)	517	25	Moderately inward
Myanmar	95	10 325	39 187	0.26	18 500 (1975)	6	n.a.	n.a.
Chile	136	20 682	12 536	1.65	69 946 (1970)	2321	35	Moderately outward
Argentina	167	108 826	31 221	3.49	695 000 (1988)	6563	26	Strongly inward
Tunisia	106	9604	7639	1.26	81 000 (1992)	1422	25	Moderately outward
Cuba	99	19 262	10 301	1.87	139 469 (1981)	1	n.a.	n.a.
Equador	136	10 527	9561	1.10	245 256 (1990)	982	34	n.a.
Egypt	164	62 932	49 050	1.28	1 573 118 (1990)	5700	33	n.a.
Iran	136	279 163	50 662	5.51	294 647 (1982)	857	n.a.	n.a.
Indonesia	164	75 932	172 010	0.44	639 006 (1991)	24 971	n.a.	Moderately inward
Peru	164	44 014	20 261	2.17	291 812 (1981)	1152	58	Strongly inward
Philippines	164	33 307	57 356	0.58	1 770 762 (1980)	1302	33	Moderately inward
India	167	257 060	781 374	0.33	2 471 400 (1990)	1075	n.a.	Strongly inward
Turkey	164	88 353	52 339	1.69	708 000 (1980)	360	n.a.	Moderately outward
South Korea	167	131 816	41 575	3.17	94 171 (1981)	1806	24	Strongly outward
Brazil	201	294 311	137 177	2.15	1 362 206 (1980)	25 665	76	Moderately outward
Former Yugoslavia	201	71 017	23 417	3.03	563 312 (1988)	179	n.a.	Moderately inward

Sources: UNIDO Global Report 1990/91, World Development Report 1987, UN Statistical Yearbook, UN Yearbook of Population Statistics, UNESCO Yearbook (various issues), UNCTAD World Investment Report 1996, Erzan *et al.* (1989).
Note: n.a., not available.